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U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF ENTOMOLOGY—BULLETIN No. 123.
L. O. HOWARD, Entomologist and Chief of Bureau.

A PRELIMINARY REPORT ON THE SUGAR-BEET WIREWORM.

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BY

JOHN E. GRAF,

Entomological Assistant,
Truck Crop and Stored Product Insect Investigations.

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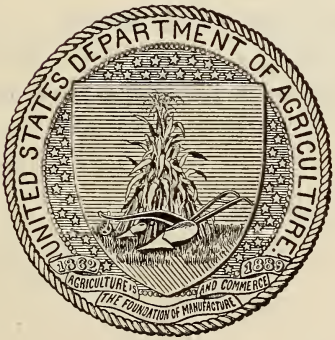

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Entomology,
Washington, D. C., February 24, 1913.

Sir: I have the honor to transmit herewith the manuscript of a paper entitled "The Sugar-Beet Wireworm (*Limonius californicus* Mannh.)," by John E. Graf, an entomological assistant of this bureau.

This very active enemy to the sugar beet in the Pacific region has been the subject of study in the Bureau of Entomology since 1909. The present paper is somewhat preliminary in character, but so many facts have been learned that it is believed advisable to submit them for publication at the present time. While this wireworm has been known in America for many years, no good report of its injuries was available until very recently. The paper sets forth the manner of injury, the history of the species, the insects associated with it in the destruction of the beet roots in different stages of growth, the number of its food plants, its life history and habits, suggestions as to the methods for its control, and other useful data, and is well illustrated.

I recommend the publication of this manuscript as Bulletin No. 123 of this bureau and would urge that it be issued at an early date, as there is great demand for information on the part of the sugar-beet growers of the country, all of whom are more or less troubled by the ravages of wireworms.

Respectfully, C. L. Marlatt,
Entomologist and Acting Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

The present bulletin is intended as a preliminary report of the investigations which have been carried on with the sugar-beet wireworm (*Limonius californicus* Mannh.) since 1909. The life-history work has not been completed; in fact it was not until the spring of 1912 that it could be started on a scale which gave any promise of ultimate success. As tests of many of the control measures were finished during the latter part of 1912, and as it will be several years before a complete study can be finished, it has been decided to publish a report at this time giving all the observations and experiments which have been carried on thus far.

During the coming years, in addition to the completion of the life-history studies, work will be carried on with other control measures. The relation of the birds of the sugar-beet fields to the wireworms will also be investigated, as will the bacterial and fungous diseases which have been observed to affect this species.

The author wishes to acknowledge his indebtedness to Dr. F. H. Chittenden and Mr. H. M. Russell for assistance and suggestions throughout the work. Mr. Russell began the study of *Limonius californicus* in 1909. The cooperative work of Mr. R. S. Vaile, of the Ventura County horticultural commission, and Prof. H. S. Fawcett, of the University of California, is also deserving of grateful acknowledgment.

J. E. G.

CONTENTS.

	Page.
Historical	11
Losses due to the sugar-beet wireworm	11
Insects found with the sugar-beet wireworm	12
Classification, synonymy, and common names	13
Descriptions	14
The adult	14
The egg	14
The larva	14
The pupa	15
Distribution	16
Food plants	16
Life history and habits	18
The egg	18
Time and place of deposition	18
Number and hatching of eggs	19
Length of egg stage	20
The larva	20
Emergence from the egg	20
The newly hatched larva	20
Rearing cages used	21
Habits of the young wireworms	22
Approximate length of larval stage	24
Habits of the older wireworms	25
Location of food by the wireworms	25
Activity of the wireworms	26
Wireworm injury to beets	26
Time the wireworms can live without food	27
Relation between injury in the beet fields and the size and abundance of wireworms	29
Molting of the wireworms	29
The pupa	30
Pupation	30
The pupal cell	30
Soil conditions affecting pupation	30
Vitality of the pupa	31
Changes in color of the pupa	31
Length of the pupal stage	31
The adult	32
Emergence of the adult	32
Period of emergence	32
Actions directly after emergence	32
Appearance of beetles in the spring	33
Beginning of the period of activity	33
Variation in the size of beetles	34

Life history and habits—Continued.
The adult—Continued. Page.
Variation in the color of beetles ... 34
Feeding of the adults, and food plants ... 35
Styles of rearing cages used ... 36
Duration of life under varying conditions ... 37
Length of time adults can be submerged ... 38
Effect of temperature on the adults ... 39
Ability of the adults to withstand unfavorable conditions ... 40
Method and time of mating ... 40
Actions of the adults after mating ... 41
Oviposition ... 42
Approximate length of the life cycle ... 42
Seasonal history ... 42
Beetles from emergence to hibernation ... 42
Hibernation ... 43
Mortality during hibernation ... 43
Gradual emergence from hibernation ... 43
Secondary hibernation ... 44
Occurrence of beetles in the field ... 45
Effect of food in the field on dissemination ... 45
Other factors governing dissemination ... 46
Natural control ... 46
Enemies and checks to the beetles ... 46
Enemies and checks to the larvæ ... 48
Fungi affecting the pupæ and eggs ... 49
Remedial measures ... 50
Historical ... 50
Tests of suggested remedies against the sugar-beet wireworm ... 50
Attempts to destroy the adults with poisoned baits ... 50
Fall plowing for destruction of the pupæ ... 51
Experiments with deterrents against the wireworms ... 52
The use of potassium cyanid against the wireworms ... 59
Experiments with poisoned bait against the wireworms ... 60
Experiments with guano fertilizer ... 61
Protection of beets by early planting ... 61
Clean culture against the adults ... 61
Summary ... 64
Bibliography ... 64
Index ... 65

ILLUSTRATIONS.

PLATES.

		Page.
PLATE I.	Adults of the sugar-beet wireworm (*Limonius californicus*), showing variation in size	12
II.	Stages of the sugar-beet wireworm. *Fig. a.*—Adult. *Fig. b.*—Newly hatched larvæ. *Fig. c.*—Eggs	12
III.	A sugar-beet wireworm in process of molting	12
IV.	Wireworms and wireworm-like larvæ	12
V.	Pupa of the sugar-beet wireworm	16
VI.	Injury by the sugar-beet wireworm to germinating beans	16
VII.	Injury by the sugar-beet wireworm to germinating bean, enlarged	16
VIII.	Fig. 1.—Sugar-beet wireworms in petri dish, killed by bacteria in cultures of agar. Fig. 2.—Root cage used in rearing young wireworms	20
IX.	Work of the sugar-beet wireworm. Young sugar-beets, showing injury by wireworms to taproots; blackened feeding marks visible on end of roots	24
X.	Work of the sugar-beet wireworm. Nearly mature beets killed by wireworms; blackened feeding marks noticeable on taproots	24
XI.	Work of the sugar-beet wireworm. Mature beets, showing old scars resulting from wireworm injury	24
XII.	Ravages of the sugar-beet wireworm. Beet field, showing small cleared space resulting from the work of wireworms	24
XIII.	Ravages of the sugar-beet wireworm. Beet field, showing cleared spaces resulting from the work of wireworms	24
XIV.	Ravages of the sugar-beet wireworm. Beet field, showing cleared spaces, more extensive than in Plate XIII, resulting from the work of wireworms	24
XV.	Ravages of the sugar-beet wireworm. Beet field, showing very large cleared space resulting from the work of wireworms	24
XVI.	Adult of the sugar-beet wireworm issuing from pupal skin	32
XVII.	Habits of beetles of the sugar-beet wireworm. Fig. 1.—Beetles of the sugar-beet wireworm in secondary hibernation under slice of sugar beet. Fig. 2.—Beetles of the sugar-beet wireworm photographed while feeding on slices of sugar beet	32
XVIII.	Secondary hibernation of the sugar-beet wireworm. Beet tops used by beetles as quarters for secondary hibernation	36
XIX.	Fig. 1.—Field of young beets at age when they begin to be partially safe from severest injury by the sugar-beet wireworm. Fig. 2.—Beet field showing conditions favorable for increase of wireworms. Weed hedges which shelter adults in secondary hibernation	60
XX.	Conditions favoring the sugar-beet wireworm. Beet field immediately after harvest, showing beet tops carelessly scattered over ground	60

Page.

PLATE XXI. Clean culture against the sugar-beet wireworm. Natural method of clearing off beet tops, by pasturing cattle in the field, which has been inclosed by a temporary fence 60

XXII. Clean culture against the sugar-beet wireworm. Collecting the beet tops in piles and hauling them from the field as food for stock 60

XXIII. Conditions favoring the sugar-beet wireworm. Fig. 1.—Beet fields separated by a strip of alfalfa. Fig. 2.—Field of alfalfa adjoining field of sugar beets 60

TEXT FIGURES.

FIG. 1. The sugar-beet wireworm (*Limonius californicus*). Details of larva. 15

2. Map of California showing counties from which the sugar-beet wireworm has been reported 17

3. Injury by sugar-beet wireworm to field of sweet corn, Dominguez, Cal. 18

4. Diagram showing the period eggs of the sugar-beet wireworm were in the soil, with temperature; season of 1912, Compton, Cal 19

5. Janet ants'-nest plaster-of-Paris cage, used in rearing sugar-beet wireworms 22

6. A sugar-beet wireworm devouring one of its own kind; to illustrate cannibalistic habit 25

7. Diagram showing length of life of sugar-beet wireworm without food .. 28

8. Screen cage used in observing oviposition of adults of the sugar-beet wireworm under field conditions 36

9. Diagram of beet fields, to illustrate the effect of clean culture in reducing injury by the sugar-beet wireworm 63

THE SUGAR-BEET WIREWORM.

(*Limonius californicus* Mannh.)

HISTORICAL.

The sugar-beet wireworm (*Limonius californicus* Mannh.) has been known in the coast lowlands of southern California for many years, having been more or less destructive to sugar beets during the time they have been grown here, and prior to that time was known as an alfalfa and corn pest. In many localities the alfalfa had to be plowed up and replanted every few years, as the ravages of this larva so thinned it out that only a partial crop could be harvested unless replanting was resorted to at intervals. Owing to the fact that the ground in the alfalfa fields is nearly always damp to the surface, the wireworms seldom worked deep, and while they tunnelled through the crown of the plant, it was only a chance injury or a heavy infestation that could make itself felt, so that its destructive powers in the alfalfa fields is proof enough of its abundance.

The wireworm has also been noted as a corn pest for years, many growers reporting that on occasions it has been impossible to secure an average crop even with several plantings. Mr. Nelson Ward, of Compton, reports that on pulling up cornstalks he has discovered from 17 to 30 wireworms burrowing through the roots and into the crown of a single plant.

LOSSES DUE TO THE SUGAR-BEET WIREWORM.

There is great variation in the estimates of losses ascribed to this insect, and very probably the correct estimate would run far above the others. The reason for this is that unless the injury is exceptional it is likely to go entirely unnoticed. When the wireworms work scatteringly, their injury is apparent only to the observer who is looking especially for it, and at the right time. The writer bases this assertion on observations made during the early spring of 1912. At this time the adults were being collected, and as several hundred acres of beet fields were carefully gone over several times, it was possible, by close observation, to get a good estimate of the progress of the injury and the total damage done.

The sugar beets were quite small, having just been thinned, and were consequently at just the right age to receive the greatest injury. The roots were simple, not having swelled, and wherever a beet plant was attacked it was generally killed, as the roots were almost invariably severed by the feeding of the wireworms. All the plants which were noted wilting down were examined, and always with the same

result, viz, the tender taproot was cut and blackened and a search generally revealed the offender, a wireworm, in the soil near by. A great amount of just such work was noted, but it differed from that of 1911 in that it was more scattered.

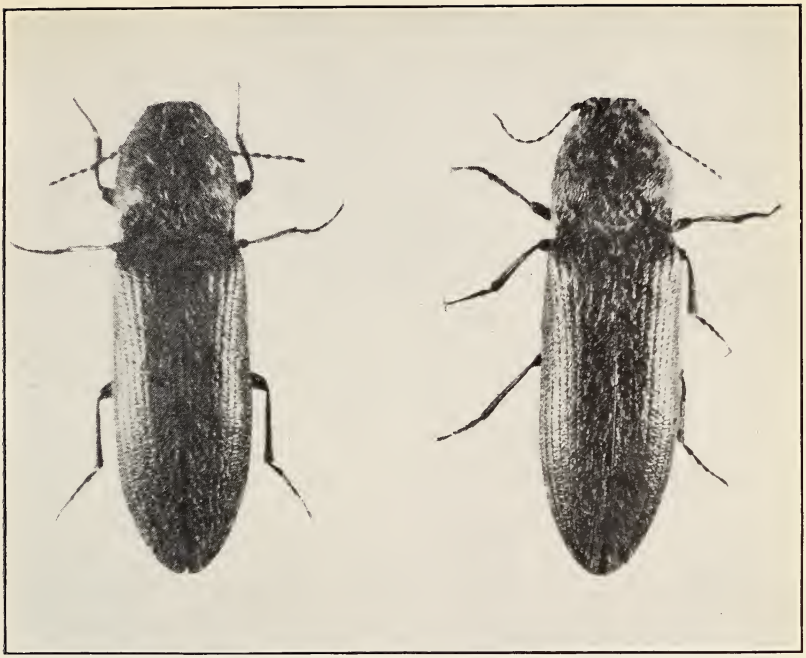
In 1911 the wireworms seemed to be working in groups, and many spots of varying size were completely cleared of beets. In 1912, however, the fields were almost entirely free from this type of work. Places were observed where from three to six beet plants had been killed in one group, but by the time the beets are mature their foliage so covers the ground that all trace of the injury is lost to the casual observer. One incident will illustrate this point. A small beet field of 10 acres located near the laboratory was carefully watched that some idea might be gained of the progress and time of injury. Every day many of the plants were found dead, but seldom were more than three or four plants killed in a place. While this injury was considerable it was kept well scattered. At the time of the last examination the beets, then nearly ripe, so covered the ground with their foliage that even where several adjoining plants had been killed it was difficult to find any signs of the injury. This shows that it is an easy matter to overlook the destructive power of this wireworm.

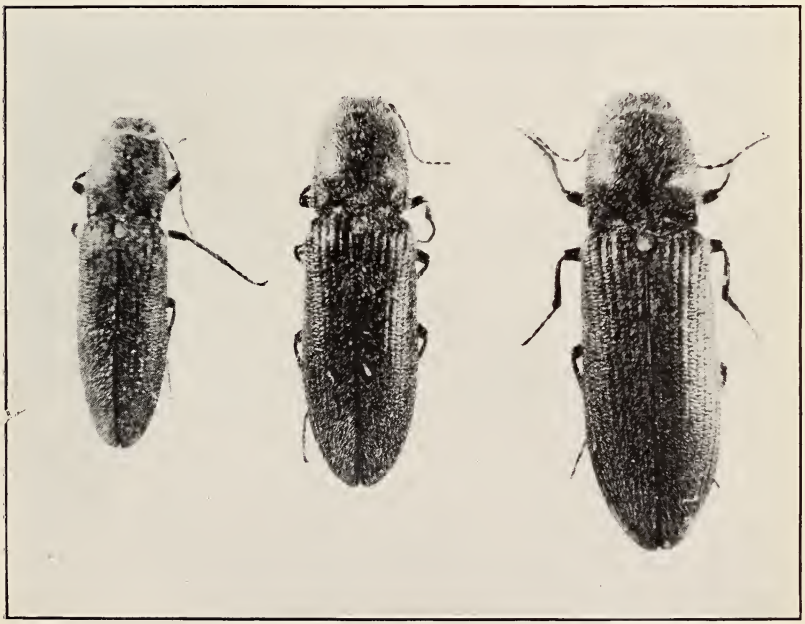
The sugar-beet wireworm may be considered the worst insect enemy of the sugar beet in southern California at the present time. It has this distinction for two reasons: First, it is constant, appearing every year to a greater or less extent; and, second, its injury occurs in such a manner that replanting is generally impracticable, or at least of little value. While beets and alfalfa appear to be the favorite food plants, the sugar-beet wireworm is also very injurious to corn (fig. 3, p. 18) and beans (Pls. VI, VII).

It would be a difficult matter to figure the loss due to the wireworm, either in percentage of the crop, tons, or dollars, but an approximation will show its importance economically. Mr. R. S. Vaile, horticultural commissioner of Ventura County, in his annual report for 1912, places the loss to lima beans alone in his county at $10,000. For 1913 he estimates the loss at $25,000 or more. If the other counties where this wireworm is destructive are taken into consideration it will be seen that probably the lima-bean growers alone lose at least $50,000 a year by this insect. Add to this the loss to sugar beets, which is probably even greater, and it is readily seen that this wireworm presents no small problem in southern California.

INSECTS FOUND WITH THE SUGAR-BEET WIREWORM.

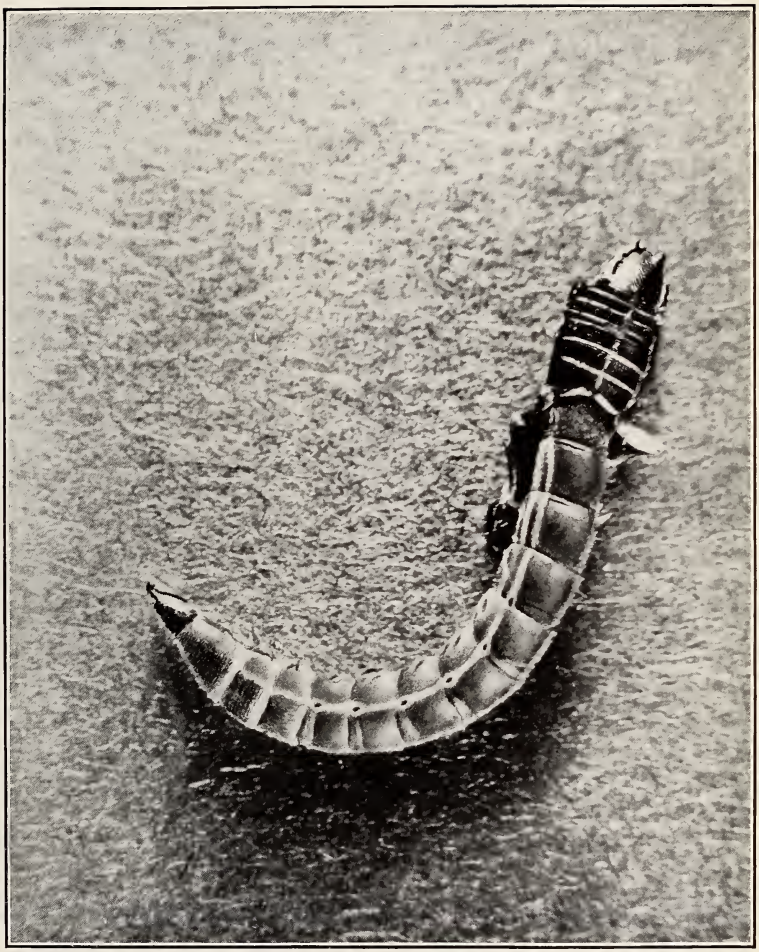
Collections of wireworms in the beet fields of southern California show at a glance that they are made up of several species. These differ widely in appearance, hence there is little chance of their being mistaken for one another. Two of them, *Limonius californicus* Mannh. and *Drasterius livens* Lec., are of the waxy color usually found in



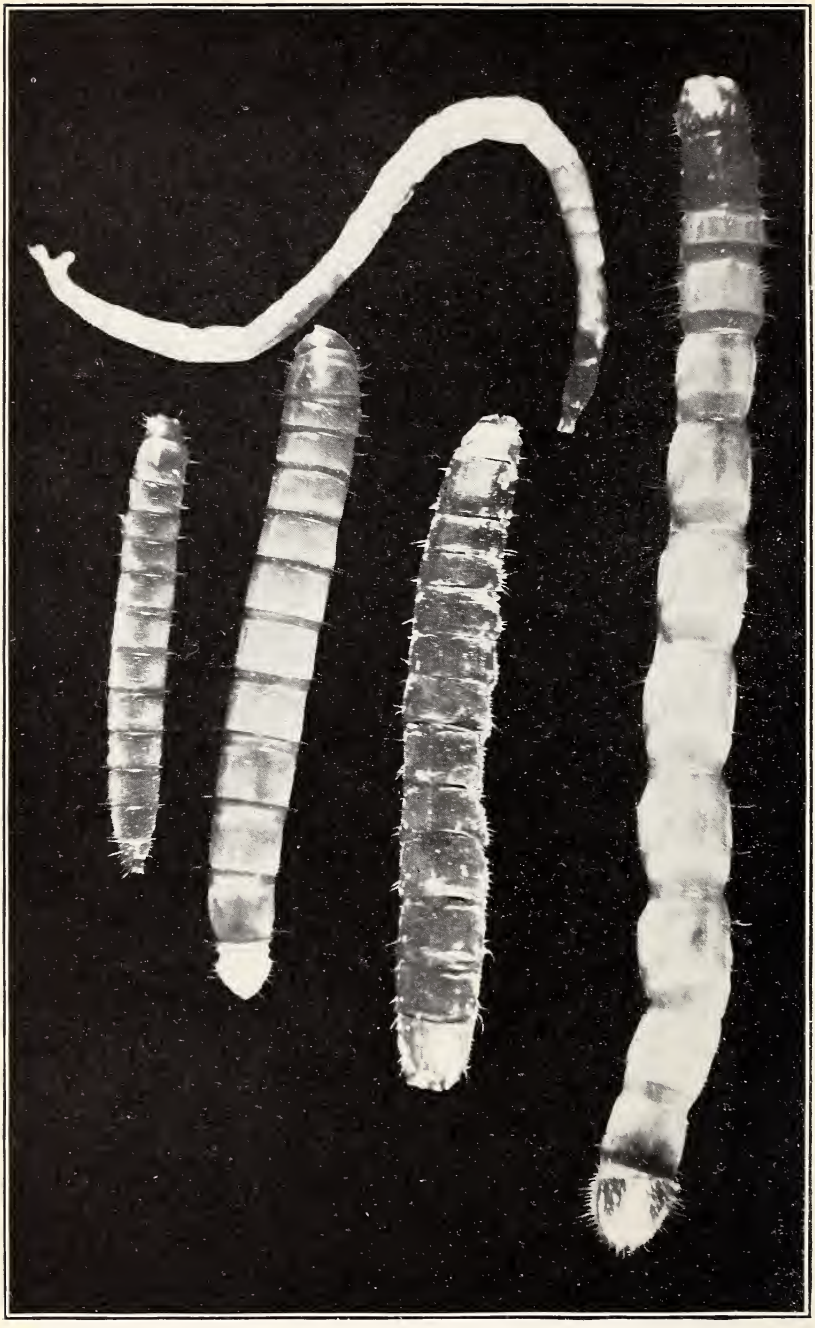


ADULTS OF THE SUGAR-BEET WIREWORM (LIMONIUS CALIFORNICUS), SHOWING VARIATION IN SIZE. (ORIGINAL.)

STAGES OF THE SUGAR-BEET WIREWORM. FIG. *a*.—ADULT. FIG. *b*.—NEWLY HATCHED LARVÆ. FIG. *c*.—EGGS. (ORIGINAL.)



A SUGAR-BEET WIREWORM (LIMONIUS CALIFORNICUS) MOLTING; THE CAST-OFF SKIN SHOWING NEAR THE ANAL PLATE. (ORIGINAL.)



WIREWORMS AND WIREWORM-LIKE LARVÆ; THE SUGAR-BEET WIREWORM (LIMONIUS CALIFORNICUS) BEING THE THIRD LARVA FROM THE LEFT, AND THE LARGE ONE AT THE RIGHT BEING A FALSE WIREWORM. ABOVE IS A DIPTEROUS PARASITE. MAGNIFIED. (ORIGINAL.)

wireworms. The latter is considerably the smaller of the two, and only an occasional individual has come under observation. The other wireworms are white, with a slight yellow tinge. Two of them belong to the genus Cardiophorus, one having been identified by Mr. E. A. Schwarz, of this bureau, as *Cardiophorus æneus* Horn. The other has not yet been reared, but as several adult specimens of *C. crinitus* Blanch. have been taken in the fields, it is probable that it belongs to this species. The other wireworm found in the fields is a large, robust, whitish one, considerably larger than *Limonius californicus*. This has not been reared and remains undetermined.

In the spring, when the adults are found in the beet fields, four other elaterids are found with them, though in lesser numbers. The most common one resembles in general characteristics *Limonius californicus*. It is of about the same size and outline, but differs from *L. californicus* in the color of its elytra, which are a decided buff instead of a deep brown. Dr. Chittenden has stated that this may prove to be a new variety of *californicus*, since, while it resembles that species quite closely, it seems to disagree in several small particulars. From the numbers of these which were found with *L. californicus* it is possible that they may be of economic importance. This species may be called the lesser sugar-beet wireworm to distinguish it from *L. californicus*.

The other elaterids which were found occurred in very small numbers, so that they may be disregarded from an economic standpoint. These have been determined as *Drasterius livens*, *Cardiophorus æneus*, and *C. crinitus*(?). These three are considerably smaller than *L. californicus* and there is therefore little chance of their being mistaken for the latter.

Another beetle commonly noted in the fields is a carabid, *Platynus* sp., slightly larger than *L. californicus*, robust, black in color, with a slight metallic tinge.

Two species of tenebrionids are also commonly found with *Limonius californicus*. Both are short, very robust, and dull black in color. One is *Blapstinus* sp., the other a species of Coniontis.

CLASSIFICATION, SYNONYMY, AND COMMON NAMES.

Limonius californicus (Pl. I; Pl. II, *fig. a*) belongs to the common genus Limonius of the family Elateridæ. It further belongs to the tribe Elaterini and group Athoi.

It was described from America in 1843 by Mannerheim as *Cardiophorus californicus* and has since been referred to the genus Limonius. *Cardiophorus californicus* is its only known synonym.

The larvæ of this entire family of insects are commonly known as wireworms. The adults, due to their habit of throwing themselves into the air when placed on their backs, have received the names "skipjacks," "click-beetles," "spring-beetles," and "blacksmiths."

DESCRIPTIONS.

The Adult.

Following is the original description by Mannerheim [1] in Latin, followed by a translation into English.

136. *Cardiophorus californicus:* elongatus niger, punctatissimus, tenue pubescens, thorace convexo, subquadrato, elytris dorso depressis, leviter punctato-striatis, sterno profunde punctato, convexo, tarsis articulis omnibus et unguiculis simplicibus.
Longit. $5\frac{1}{3}$, $4\frac{1}{3}$ lin. latit. $1\frac{2}{3}$, $1\frac{3}{4}$ lin.
Habitat in California, D. D. Blaschke et Tschernikh.

[Translation.]

Cardiophorus californicus: Elongate black, closely punctate, finely pubescent; thorax convex, subquadrate; dorsal surface of elytra depressed, feebly striate-punctate; thorax beneath deeply punctate, convex; all joints of the tarsi and claws simple.
Length $10\frac{2}{3}$–$9\frac{1}{2}$ mm., width $3\frac{1}{3}$–$3\frac{1}{2}$ mm.
Habitat, California (Blaschke and Tschernikh).

The Egg.

The egg of *Limonius californicus* (Pl. II, *fig. c*) is for the most part opaque white, though it shows small, irregular, semihyaline areas when placed on a white surface in dim light. The surface appears smooth under the low power of the microscope, but under the high power it appears to be slightly scaly. It reflects light weakly from the lighted side. That the shell is quite tough is proven by the fact that even when the eggs are rolled about in the soil they are seldom distorted.

The egg is ellipto-cylindrical in shape. Both ends are broadly rounded and resemble each other. Measurements of 30 eggs gave an average length of 0.69 mm. and an average width of 0.5 mm. The length varied between 0.63 and 0.735 mm. and the width between 0.473 and 0.53 mm.

The Larva.

The nearly mature larva of *Limonius californicus* (fig. 1; Pl. II, *fig. b;* Pls. III, IV) is subcylindrical in shape and shiny, waxy yellowish-brown in color. The segments are very minutely and sparsely punctate. The head and venter are flattened dorsally and darker in color. There is a light dorsal stripe on the posterior end of each segment with the exception of the venter.

The head is depressed and considerably narrower in front. The mandibles are strong, notched, deep brown in color, changing to black at the tip.

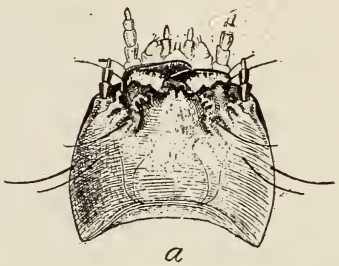
[1] Bul. Soc. Imp. Nat. Moscou, vol. 16, p. 238, 1843.

The first thoracic segment is broad and long, being about equal in length to the venter. The other thoracic segments are short, being about equal in length to the first two abdominal segments. The remaining abdominal segments are a little longer and quite similar. The legs are short and armed with heavy, short brown spines.

The abdominal segments are slightly constricted where they join one another. There are from two to four hairs on the lateral side of each segment. The spiracles are brown, conspicuous, and are situated in a poorly defined, light lateral stripe. They are slightly nearer the anterior end of the segment.

The venter is depressed dorsally, with raised edges. It is sparsely hairy around the edge. The caudal notch has a small tooth on each side pointing slightly upward and backward. The margin of the notch varies from deep brown to black.

The average length of the mature larva is from 18 to 21 mm., and the width is from 2.5 to 3 mm.



The Pupa.

When first formed the pupa is opaque white, but after a time the eyes show through as pale, dusky, blue spots. About this time the thoracic segments become a pale waxy yellow, but no other changes take place until shortly before emergence.

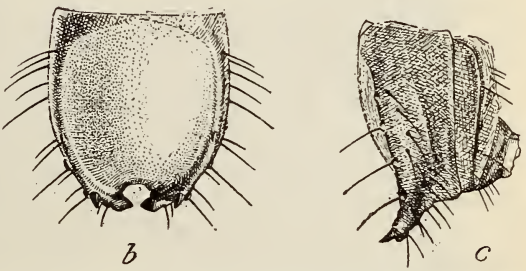


FIG. 1.—The sugar-beet wireworm (*Limonius californicus*): *a*, Head; *b*, anal segment from above; *c*, same, lateral view. Highly magnified. (Original.)

The pupa (P[illegible]) very much resembles the adult beetle in shape, except that the abdomen is slightly longer in the pupal stage. The head is bent forward slightly, and each anterior angle is armed with a long, heavy spine, which tapers regularly to a point. The mouth parts are conspicuous. The antennæ are laid along the margin of the head on the ventral side, and their tips are behind the tibiæ of the second pair of legs. On the underside of the head and near the prothorax are two short, heavy spines. There are also two short, stout spines on the dorsal side of the head near the posterior angles.

The case covering the springing apparatus is plainly visible between the anterior coxæ. The leg cases are folded similarly to

those of other Elateridæ. All of the posterior pair, excepting the tarsi, are covered by the wing cases, which are curved around and almost meet on the ventral side, at the distal end of the third abdominal segment.

The abdomen is contracted sharply at the seventh segment, so that the eighth segment is only a little more than half as wide as the anterior end of the seventh.

The anal segment bears two long, heavy spines on its posterior angles. These spines are slightly divergent, are pitted, and the distal half of each is brown, changing to black at the tip.

The pupæ vary greatly in size. Measurements taken from several individuals give an average length of 11.5 mm. and a width of 3.6 mm.

DISTRIBUTION.

This wireworm is found quite generally throughout the western half of California. It is abundant in the lower sugar-beet lands of southern California. The main districts affected by it are those of Ventura, Orange, and Los Angeles Counties. These three districts comprise probably the choicest sugar-beet land in southern California. The station for the study of this insect was located in Compton, in Los Angeles County, about 10 miles from the coast, and surrounded by about 12,000 acres of sugar beets.

Limonius californicus has been reported from the following places, all in California: Riverside, San Bernardino, Los Angeles, Lake, Monterey, and El Dorado Counties, by Prof. H. C. Fall; near Owens Lake, collected by Dr. A. Fenyes; Marin County, specimens in the collection of the University of California; Orange, Ventura, and San Diego Counties. (See fig. 2.)

Prof. A. L. Melander, entomologist of the Washington Agricultural Experiment Station, Pullman, Wash., reports that in the collection there they have a single specimen which was collected in eastern Washington.

It is thus seen that this species is fairly well scattered along the western half of California. It is probably not of economic importance outside this State.

FOOD PLANTS.

The larvæ of *Limonius californicus* have been noted to feed on the following plants:

Sugar beet.
Wild beet (*Beta* sp.).
Potato (*Solanum tuberosum*).
Lima bean (all varieties).
Corn (all varieties).
Johnson grass (*Sorghum halepense*).
Dock (*Rumex hymenosepalus*).
Alfalfa (*Medicago* spp.).
Pigweed (*Amaranthus retroflexus*).
Chrysanthemum.
Nettle (reported by H. M. Russell).
Wild aster (reported by H. M. Russell).
Mustard (*Brassica niger*).

PUPA OF THE SUGAR-BEET WIREWORM. LATERAL VIEW AT LEFT; VENTRAL VIEW IN MIDDLE; DORSAL VIEW AT RIGHT. ENLARGED. (ORIGINAL.)

INJURY BY THE SUGAR-BEET WIREWORM TO GERMINATING BEANS. ABOUT NATURAL SIZE. (ORIGINAL.)

INJURY BY THE SUGAR-BEET WIREWORM TO GERMINATING BEAN. ENLARGED. (ORIGINAL.)

It is difficult to note a preference of this wireworm for any particular food plant, as sugar beets, lima beans (Pls. VI, VII), corn (fig. 3), potatoes, and alfalfa all seem to be favored. After these

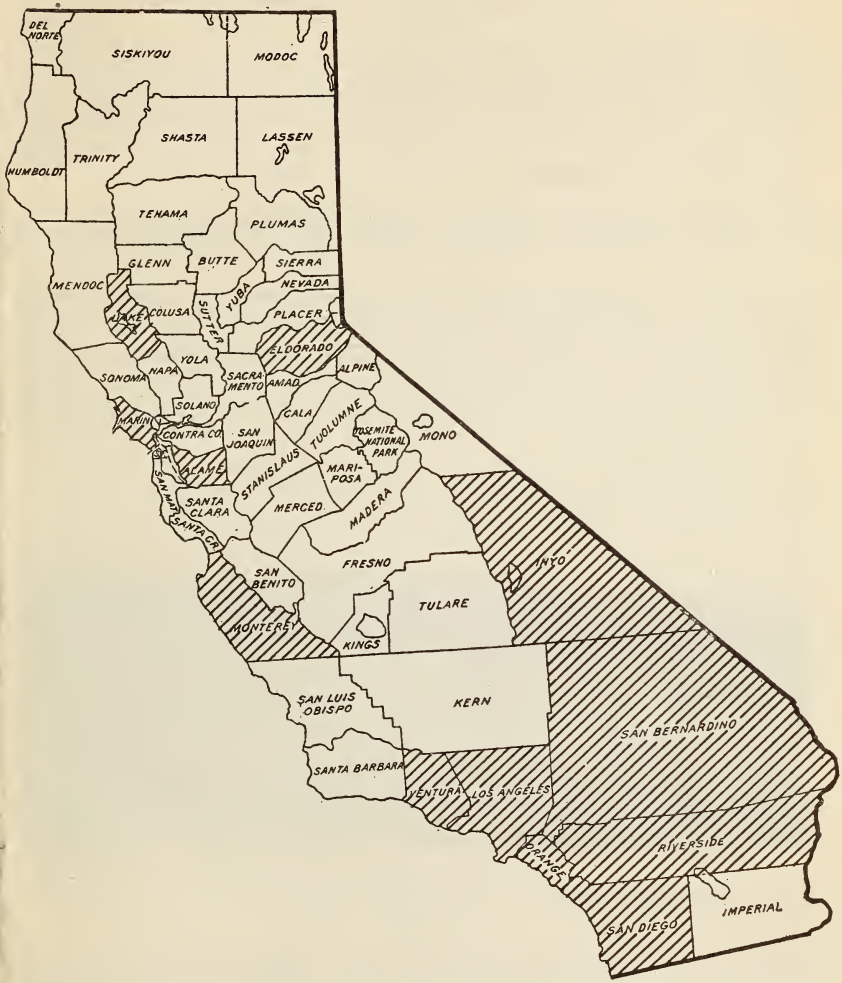


FIG. 2.—Map of California showing counties from which the sugar-beet wireworm has been reported. (Original.)

in order come Johnson grass and wild beets. The remaining food plants seem to be taken more from necessity than choice, and it is only occasionally that larvæ are discovered feeding on them.

LIFE HISTORY AND HABITS.

The Egg.

TIME AND PLACE OF DEPOSITION.

The eggs (Pl. II, *fig. c*) are all deposited during the spring and in the greatest numbers about the middle or latter part of April. (See diagram, fig. 4.) During the latter part of March immature eggs to the number of from 25 to 40 could be dissected from the swollen abdomens of the females.

On April 9 the first eggs were laid. These were placed in the loose damp soil of the rearing cages, about 1½ inches below the

FIG. 3.—Injury by sugar-beet wireworm (*Limonius californicus*) to field of sweet corn, Dominguez, Cal. (Original.)

surface. It seems that it is intended that the eggs shall always be placed singly, as out of about 8,000 eggs taken from the soil only a very few cases were noticed where several eggs were together. Never were more than three eggs in a group, and these were not held together in any way.

Food plants seem to have no effect on the place of deposition, as there were always as many eggs found at the edges of the cage as there were surrounding the young beet plant at the center. At first this was supposed to be due to the fact that the tender root hairs are scattered rather generally through the soil, but later tests seemed to indicate that the place of deposition is affected more by the con-

dition of the soil, a loose damp soil being selected by the adults in preference to other kinds.

Nearly all the eggs were placed in the first inch and a half of damp soil, and the greater part of these about 1 inch below the line of dampness.

A small mite, which has been identified by Mr. Nathan Banks as (*Gamasus*) *Parasitus coleoptratorum* L. (?), was commonly noted in the soil with the eggs but was never seen destroying them.

NUMBER AND HATCHING OF EGGS.

Complete records for the eggs could not be obtained, so the number of eggs laid by a female of this species is still a question. One female which had been isolated after fertilization laid 71 eggs before death, and 11 were added by dissection, bringing the total to 82 eggs. Another female gave a total of 63 eggs by oviposition and dissection. Two others gave 61 and 52 eggs. Twenty-five dissections gave the number of eggs as between 28 and 40, or an average of about

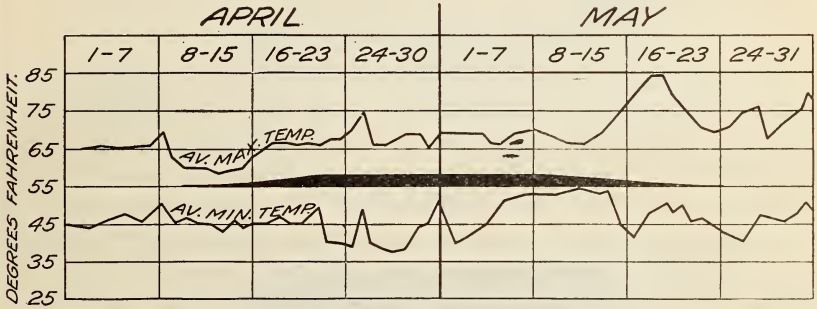


FIG. 4.—Diagram showing the period eggs of the sugar-beet wireworm were in the soil, with temperature; season of 1912, Compton, Cal. (Original.)

34 eggs per individual. It is quite probable that 100 eggs or even more may be deposited by a single female.

Practically all the eggs hatch. In the laboratory over 94 per cent of 5,000 eggs hatched successfully, even after they had been handled and kept under artificial conditions. Those which did not hatch were for the most part either allowed to dry out or were killed by a fungus. Eliminating two cages—the one which dried out and the one in which the fungus appeared—it would be safe to say that over 98 per cent of about 4,200 eggs which were kept under laboratory conditions hatched safely.

There is an optimum zone, in so far as the degree of dampness is concerned, for the hatching of the eggs. Some eggs kept in a dry vial indoors, where it was not too warm, failed entirely to hatch and after a time shriveled up. On the other hand, the eggs which were kept too damp were subject to a fungous attack. Water itself

seems to have little effect on the hatching of the eggs, as some which were kept partially submerged part of the time hatched in good shape.

As hatching time approached, large, irregular, hyaline areas appeared in the eggs in various places. At first nothing could be seen of the embryo, but about a week before hatching its outlines could be made out with difficulty. The embryo became little plainer, even at the time of hatching.

LENGTH OF EGG STAGE.

The length of the egg stage varied under laboratory conditions from 23 to 33 days, most of the eggs hatching in from 27 to 30 days, so that the length of the egg stage may be roughly considered as a month. It seems probable that the period might be shortened materially under favorable conditions, out of doors, and eggs laid in the warm damp soil might possibly hatch in from 15 to 25 days.

THE LARVA.

EMERGENCE FROM THE EGG.

The larvæ (Pl. II, *fig. b*) emerge from the eggs by eating a small hole in the shell and crawling out. In all the cases noted the hole was very little larger than the body of the wireworm, so that it is a matter of a few moments for the young wireworm to leave the shell entirely. In the case of several which were timed, between two and seven minutes elapsed from the appearance of their heads through the shell until they were entirely free. During the earlier part of the hatching season no eggshells could be found, and it was thought probable that the larva on emerging used the shell for food. Such did not prove to be the case, however, as later, when more eggs were hatching, it was observed that the larva on hatching leaves the old shell almost at once. In a few cases the larvæ crawled around the shells for a short time but did not attempt to eat them and always left them intact. Where the eggs are hatching in the soil, the young larva remains for a short time in the cavity occupied by the egg. That the eggshells are quite tough was proven by the fact that the empty shells were able to retain their shape for some time.

THE NEWLY HATCHED LARVA.

When first hatched the larva (Pl. II, *fig. b*) is semiopaque white. The extreme tips of the mandibles are the only parts which show any color, and these are light yellow. The general proportions of the newly hatched larva are very much like those of the older ones. They vary little in size. Their average length is 2 mm. and the width is 0.27 mm.

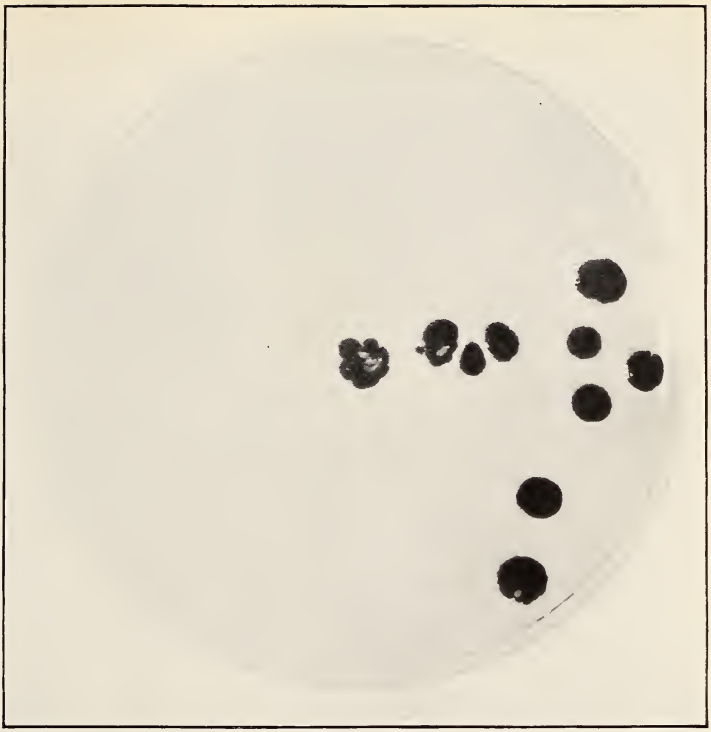


FIG. 1.—SUGAR-BEET WIREWORMS IN PETRI DISH, KILLED BY BACTERIA IN CULTURES OF AGAR. (ORIGINAL.)

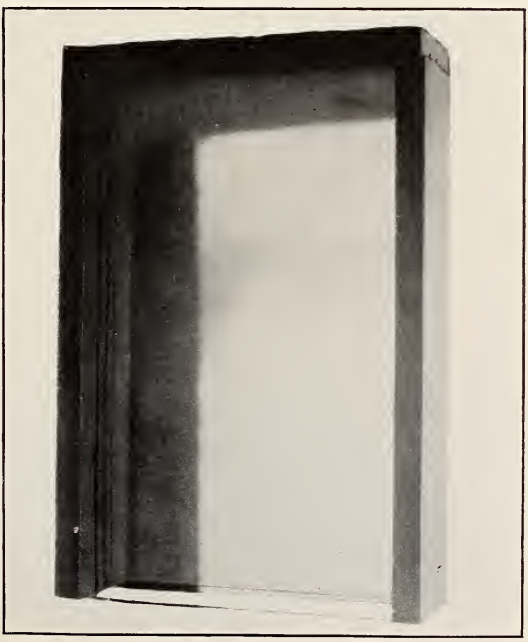


FIG. 2.—A ROOT CAGE USED IN REARING YOUNG WIREWORMS. (ORIGINAL.)

When these larvæ are exposed to a moderately subdued light they color quite rapidly and become noticeably yellow all over their bodies in a day's time. When the newly hatched larvæ are kept in darkness they color more slowly, and two or three days elapse before their bodies become yellowish. Their skin is quite tender, but in spite of this they can survive rather rough handling.

REARING CAGES USED.

Several styles of cages were used in an endeavor to find one in which the wireworms could be successfully reared and at the same time watched. Only three types gave any promise of success, and these will be reviewed briefly.

The first type used was simply a petri dish with damp filter paper in it. Several sheets of filter paper were used so that when the larvæ crawled between the sheets it was almost the same as if they were in damp soil. Slices of beets were placed in the cage and renewed daily. These were of use not only as food for the wireworms, but they also assisted in keeping the atmosphere of the dish damp and cool. These dishes were then kept in insect boxes to insure perfect darkness and to assist in keeping the temperature even. This style of rearing cage was very successful for the first two weeks, and much was expected of it, but from that time on one bad point after another presented itself, and within a month the cage was given up as impractical. The two worst points in connection with this cage are that the amount of moisture can not be regulated and, secondly, that there is no drainage and the cage tends to foul easily. The cages were cleaned every day and fresh filter paper added, but in spite of all these precautions a red bacterium (Pl. VIII, fig. 1) made its appearance in several of the cages at about the same time, and as there seemed to be no way to check it this style of cage was given up.

Another rearing cage (fig. 5) which was used was made of plaster of Paris, and was patterned after the Janet ants' nest, except that it was more simple. It is a plaster-of-Paris block with two depressions in it. Water is kept in one and the wireworms in the other. The water readily soaks through the block, and if the dish is covered with a tight-fitting piece of glass the depression containing the wireworms is kept damp and cool. The cage is further improved by painting the glass plate black to exclude light. Dr. Chittenden suggested a coating of paraffin for the outside of the dish to cut down the excessive evaporation. This scheme worked well where only part of the dish was coated. Whenever the entire outside of the cage was coated, however, the drainage was cut off, the cage became foul, and the wireworms died. The great advantage of this cage, as pointed out by Messrs. Knab and Dimmock, is that it can be sterilized simply by heating. Most of the first trials of this cage were failures,

but it soon gave promise of being a simple and safe receptacle in which to rear wireworms.

The other style of cage was the common root cage (Pl. VIII, fig. 2), so often used for the study of underground insects. The cages used in these experiments had the glass walls very close together (one-eighth to one-fourth inch) so that there would not be much soil in which the larvæ could hide. The root cages were not so successful as it was hoped they would be, for the larvæ were usually able to conceal themselves and it seemed almost impossible to wet the cages properly. Used in conjunction with the other cages, however, they gave fair success.

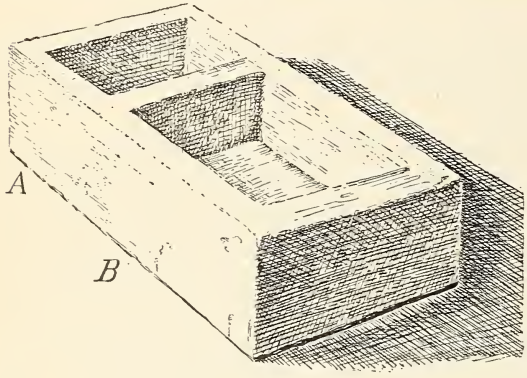


FIG. 5.—Janet ants'-nest plaster-of-Paris cage, used in rearing sugar-beet wireworms. *A*, compartment for larvæ; *B*, compartment for water. (Original.)

The majority of the young wireworms were kept in large flowerpots, so that in case of accidents to the rearing cages not all the larvæ would be lost. These pots had an added advantage in that they provided soil conditions quite similar to those out of doors. The flowerpots were emptied and examined from time to time so that the larvæ could be watched.

HABITS OF THE YOUNG WIREWORMS.

The young wireworms are quite active, moving over smooth surfaces or burying themselves in the loose soil with ease. Some placed in a root cage buried themselves almost at once, but were temporarily checked by a layer of compact earth about an inch below the surface. On the following day several had entered the compact layer and the next day one was noted at a depth of 4 inches.

When very young they are unable to survive in dry earth even for a relatively short time. Some which were placed in a petri dish with dry soil were dead at the end of five hours, a few dying after the first hour and a half.

These larvæ shun the light and when exposed to it hide under any object which they can find. When placed in the petri-dish cages they soon crawl between the layers of filter paper at the bottom. Experiments were made to test their ability to locate food, by placing a slice of sugar beet in the cages and noting the time it took them to collect under it. The beet slice was not larger than a dollar and was

placed in the center of a large petri dish. Within 10 minutes all the wireworms were under it. This experiment was repeated by using a piece of damp cardboard the size of the beet slice and again timing the wireworms. In this test all the larvæ finally gathered under the cardboard to escape the light, but a longer time was required before this took place. These tests were repeated several times as checks and always gave the same results, so it is evident that the larvæ are able, to a small extent, to locate food.

The larvæ begin feeding noticeably, though lightly, very soon after hatching. A fresh slice of sugar beet was placed in the cage every day, and when each slice was removed the minute black feeding marks could be noticed. The depressions made by the feeding could be made out only with a hand lens, but the black stain, so characteristic of wireworm injury, had spread out and was quite conspicuous.

The wireworms grow quite rapidly during the first two or three weeks, and it might be added that this is the only time in their long larval life when their growth is apparent. They approximately double in size in this time and then remain about the same size until they molt. At the time of their first molt they take a sudden jump in size and from this time on their growth is very slow.

An attempt was made to trace the molts with these wireworms, but unfortunately it had to be abandoned. The death rate in the exposed cages was so high that it soon became apparent that none could be brought entirely through in this manner. Added to the difficulty was the fact that since their time of molting was so irregular only a few could be kept in a single cage. After about a thousand larvæ had died in these cages it was concluded that it was impossible to carry the observations to completion with the forms of rearing apparatus at hand. The cast skins of the larvæ could not be found, owing to their small size and transparency, and the only molts that could be traced were in the case of certain larvæ which increased in size quite noticeably overnight. The increase in the width of the head was found to be the best test.

From time to time the soil in the flowerpots containing the bulk of the wireworms was carefully examined to see whether anything could be learned concerning the feeding habits of the larvæ under natural conditions. In every case the larvæ were found scattered rather generally through the soil, and as many of them were found around the edges of the pot as directly around the beet root. Since the root hairs were scattered pretty generally through the soil it seemed probable that the larvæ fed on them. This was further indicated by the fact that no feeding marks could be found on the main beet root. At any rate it is safe to say that, from the standpoint of injury due to their feeding, the wireworms during the first year of their larval life may be disregarded. Larvæ were generally found from 1 to 3

inches below the surface, but as the soil in the rearing cages was kept damp to the surface they would evidently be found deeper under field conditions.

Examination from time to time during the summer revealed no startling changes. Growth was very slow, but the wireworms became more active, and their skins a deeper yellow and noticeably harder.

APPROXIMATE LENGTH OF LARVAL STAGE.

As the first larvæ of this species were hatched from the eggs in the spring of 1912 there are no data concerning the complete life history or even of the way the larvæ pass their first winter. At the date of this writing (Oct. 15, 1912), however, it seems quite evident that this year's wireworms will turn out next spring to be the "small ones" which are always noted coming up to feed during February and March.

At the time the beetles were being collected, in March, 1912, there was no vegetation of any kind in some of the fields, and the wireworms, coming out from hibernation, were attracted to the old beet roots which are found in greater or less numbers in all of the fields. Nearly all larvæ collected at this time, to the number of over 3,000, were readily separable into two sizes. This has been reported before by other investigators.[1] The smaller ones appeared to be about one-third grown, and very probably were the ones which had hatched the preceding spring, and were consequently about a year old. The larger ones showed more variation in size, occurring from three-fourths grown to practically mature. These larvæ were probably 1 and 2 years older than those of the smaller size. That there is a difference in age in the wireworms of this latter group is proved by the fact that of 100 isolated during March only 17 pupated in the period from July to September, and the remainder, some of which at the time of writing (December, 1912), had recently molted, had gone deep into the soil in the cages and seemed prepared to spend the winter. Now, from the fact that none of these large larvæ could have come from eggs the preceding spring it seems very probable that this species will uphold the contentions of most of the American writers on this subject and spend three years in the larval state. To be exact, it would be a trifle over three years, as Prof. F. M. Webster[2] has pointed out, "the larvæ hatching in the spring and pupating in the late summer." Larvæ have also been carried in the laboratory from June, 1910, to April, 1912, without pupating, so it seems evident that the larval stage could not be less than three years.

[1] Eleventh Report on the Noxious, Beneficial and other Insects of New York. By Asa Fitch. M. D., 1866.

[2] Underground Insect Destroyers of the Wheat Plant. By F. M. Webster. Bul. 46, Ohio Agr. Exp. Sta., 1892.

WORK OF SUGAR-BEET WIREWORMS. YOUNG SUGAR-BEETS, SHOWING INJURY BY WIREWORMS TO TAPROOTS; BLACKENED FEEDING MARKS VISIBLE ON END OF ROOTS. (ORIGINAL.)

WORK OF THE SUGAR-BEET WIREWORM. NEARLY MATURE BEETS KILLED BY WIREWORMS; BLACKENED FEEDING MARKS NOTICEABLE ON TAPROOTS. (ORIGINAL.)

WORK OF THE SUGAR-BEET WIREWORM. MATURE BEETS SHOWING OLD SCARS RESULTING FROM WIREWORM INJURY. (ORIGINAL.)

RAVAGES OF THE SUGAR-BEET WIREWORM. BEET FIELD, SHOWING SMALL CLEARED SPACE RESULTING FROM THE WORK OF WIREWORMS.
(ORIGINAL.)

RAVAGES OF THE SUGAR-BEET WIREWORM. BEET FIELD, SHOWING CLEARED SPACES RESULTING FROM THE WORK OF WIREWORMS. (ORIGINAL.)

RAVAGES OF THE SUGAR-BEET WIREWORM. BEET FIELD, SHOWING CLEARED SPACES, MORE EXTENSIVE THAN IN PLATE XIII, RESULTING FROM THE WORK OF WIREWORMS. (ORIGINAL.)

RAVAGES OF THE SUGAR-BEET WIREWORM. BEET FIELD, SHOWING VERY LARGE CLEARED SPACE RESULTING FROM THE WORK OF WIREWORMS. (ORIGINAL.)

HABITS OF THE OLDER WIREWORMS.

While these wireworms were being collected in the fields there was a good opportunity to observe their feeding habits and their actions after emerging from hibernation. As the soil was wet to the surface by the intermittent rains, it was easy for the wireworms to reach the old beets which were scattered around on top of the ground. As the larvæ had just emerged from hibernation they fed extensively, with the result that whenever several wireworms attacked a beet root it was soon honeycombed with their channels. Many of the wireworms noted were buried far more than their own length in the half-rotted beets.

FIG. 6.—A sugar-beet wireworm devouring one of its own kind; to illustrate cannibalistic habit. (Original.)

These larvæ are carnivorous on occasions (see fig. 6), even under field conditions; especially is this so during the early period when they are feeding most busily, and when at the same time they tend to be crowded. Under average field conditions, however, cannibalism is unimportant from an economic standpoint, as these larvæ are vegetable feeders by choice.

LOCATION OF FOOD BY THE WIREWORMS.

Whether or not the wireworms, under field conditions, can locate food at a distance, and, if so, at what distance, is more or less problematical. When wireworms were injuring beets in the fields it was found by careful digging that all which were near the beets were actually feeding on them. Wireworms noticed in fields containing young beets were almost always found in the beet rows, in spite of the fact that the ground there is compact and unfavorable for them. These facts seem to carry out the idea gained from the experiments with the young larvæ, that they can locate food at a short distance, though this is not proven conclusively.

ACTIVITY OF THE WIREWORMS.

During the spring, when the soil is kept wet by the rains and loose by cultivation, it is probable that the wireworms are able to travel from one beet plant to another. Under laboratory conditions they have been noted to travel several inches daily, in the root cages, and the soil then is very apt to be compacted by wetting. This point was tested by placing several wireworms in a root cage without food in order to compel them to move. The soil, which was quite damp at first, was allowed to become pretty thoroughly dry, and then the cage was watered. The water followed the channels of the wireworms, and in this way the wireworms could be easily traced by the wet streaks through the soil. These cages were 18 by 24 inches, yet in the week or 10 days the soil was drying out the wireworms had been able to channel all through the soil. Late in the summer, when the soil is more dry and compact, they move about much more slowly and are less anxious to feed, but as they do all their damage in the spring their actions at the latter time are of the utmost importance. From all the observations on their activity it seems not only possible but even probable that one wireworm can destroy several young beet plants in a season. The sugar-beet plants are from 6 to 8 inches apart in the rows.

WIREWORM INJURY TO BEETS.

During the latter part of February and in March and April the ravages of the wireworms in the beet fields are very noticeable, especially so when the insects are present in numbers. In a year such as 1912, when their work was well scattered, injury can be noted, but it is possible to overlook it.

When the young beet plants are attacked they wilt, and upon examination the root is found to be either badly scarred or entirely severed. (Pl. IX.) This injury generally takes place between 1 and 4 inches below the surface. There are two general types of injury; in one the taproot is cut off clean, and the beet wilts and dies (see Pl. X); in the other the wireworm, after eating into the root, turns and descends, eating off a side of the root as it goes down (see Pl. IX). This, of course, scars the root badly, and if the beet is quite young and tender it is apt to die. If, however, the beet is quite strong and the root is swollen a little, so that the injury does not cut off the sap supply, it will recover, though always remaining distorted and undersized. (See Pl. XI.)

In years when the wireworms appear in numbers they are likely to be concentrated in certain spots. When this occurs they kill off all the beet plants in these areas, causing the characteristic "bald spots." (Pls. XII–XV.) When once they have collected in

this manner and have cleared off the beets it is almost impossible to raise beets there during that year, even if replanting is resorted to several times, as the wireworms kill them as soon as they germinate.

The injury caused by the wireworms is characteristic and should never be mistaken. In the first place, if the injury is recent, an examination will reveal the wireworm near by in the soil. If no wireworm is present an examination of the wound will readily show whether or not it is wireworm injury. The wound itself is stained black, as if rubbed with ink. Sometimes the black stain has penetrated for a short distance into the sound beet tissue, but where it has not, it is considerably darker than the dry tissue surrounding an ordinary old wound.

Effect of overflowing on the wireworm.—From the fact that wireworm injury is often noticed in fields which have been overflowed in the latter part of the winter, it has naturally been supposed that overflowing of the land is favorable to wireworms. This has not been proven to be entirely true. A careful watch was kept on the fields which are subject to overflow, and from these observations it seems that overflowing the land is of account only as it affects the character of the soil and is therefore secondary. In overflowed land which tends to be sandy the wireworms are likely to be destructive year after year. On the other hand, flooded land which is a heavy silt and rich in humus is seldom so badly injured as is sandy unflooded land. One thing has been noticed, however, and that is that flooding the land does not seem to injure the insect in the least and therefore gives little promise as a control measure. Some of the beet fields which have suffered the most during the last few years are those which almost every year are quite thoroughly flooded for two or three days.

TIME THE WIREWORMS CAN LIVE WITHOUT FOOD.

Whether or not these larvæ are able to find food in the soil is hard to determine, but judging from the length of time they are able to live without food it seems possible that they do receive some sustenance from the soil, probably in the form of decaying vegetation. This is further borne out by the fact that where larvæ are kept for a time in a cage without food all the lumps of leaf mold disappear and the soil in the cage becomes homogeneous.

Several observers have reported that these larvæ can survive long periods without food, and one example which was noted in the laboratory will furnish added proof. During June, 1910, Mr. H. M. Russell commenced a starvation experiment by placing several wireworms in a root cage, with ordinary soil, without food. In July, 1911, seven larvæ were still alive and healthy. This cage was

watered regularly, except on two occasions, during the late summer of 1911 and was then allowed to become quite dry. As the larvæ were killed by the drying soil they were removed so that they would not furnish food for the survivors. On September 12, 1911, the cage was again examined and only one larva was found alive. Two dead ones were found near the surface in the dry earth, and they had probably been killed by the drying out of the soil. This cage was then watered regularly and examined at intervals. The larva was still alive and active on April 15, 1912. During the latter part of April the cage, which was kept in the outdoor insectary, was blown over by the wind and broken. Before it was noticed the soil had dried out to such an extent that the larva was dead. An

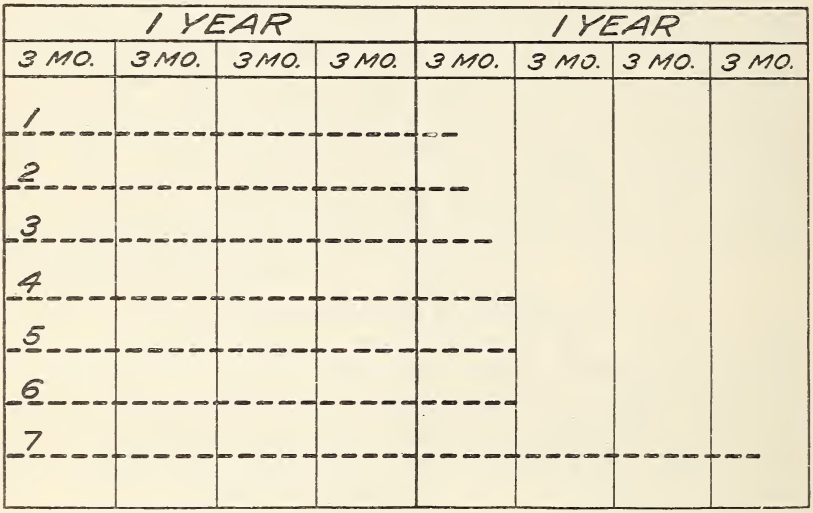


FIG. 7.—Diagram showing length of life of sugar-beet wireworm without food. (Original.)

examination of the channels through the cage showed that the wireworm had been quite active up to the time of its death. While these larvæ might have secured a little food during the earlier part of the experiment they could not have done so later, as they were checked up and removed when they died. In this experiment seven wireworms lived over a year without food, and one almost two years, as shown in the following diagram (fig. 7).

These wireworms did not grow normally, for when the last one died after being in the cage two years it was less than half size. This larva should have pupated that fall, as it was at least a year old when the experiment began, and therefore should have been mature.

RELATION BETWEEN INJURY IN THE BEET FIELDS AND THE SIZE AND ABUNDANCE OF WIREWORMS.

As is the case with practically every destructive insect, the greatest harm is done by the maturing larvæ. It is therefore only a matter of watching the progress of injury in the beet fields to tell whether or not there are many mature wireworms, and whether, therefore, there will be an abundance of beetles the following year. In every year during which observations have been made thus far it has been a simple matter to foretell this point. In 1911 injury to the beets was quite heavy and general. From this it was reasonable to suppose that there were many mature wireworms in the soil and that the next year would see an abundance of beetles. Such proved to be exactly the case, and beetles were quite common in the fields; so much so, in fact, that it was no extraordinary feat to collect over 25,000 of them for the rearing work. In 1912, in the vicinity of Compton, the wireworm injury, while quite general, was light, and using the same reasoning it was probable that there would be few beetles in the spring of 1913. This has been partially proven by the fact that very few of the larvæ taken in the fields during 1912 pupated the same fall. The 300 wireworms collected in the summer of 1911 produced almost as many pupæ in the fall of that year as the 12,000 wireworms collected in the summer of 1912 produced during the succeeding fall.

MOLTING OF THE WIREWORMS.

The wireworms molt in their channels, and wriggling from their old skin (Pl. III) they lie still for some time until their new skin has hardened. If the channel is larger in cross section at the place where the wireworms molt, it is so little larger as to be almost unnoticed. When ready to molt the larvæ lie still for some time, in certain cases for several days, before the skin splits and they are able to free themselves. In a majority of the cast skins noted the skin had split down the dorsum of the thorax. Where this occurs the process of molting is simple and seldom takes more than two or three hours. The cast skin is also in one piece. Now and then the skin splits irregularly, and in these cases the molting process requires more time, sometimes several days. In one case noted the wireworm shed the skin from its head a full week after it had molted on its thorax and abdomen. In such cases the skin is quite apt to be torn into several pieces and is almost useless for study.

Directly after molting the wireworm, with the exception of its mandibles, is a rather shiny opaque white. The mandibles are yellowish, shading to brown at the tips. The wireworms color quite well in from one to three days, but they often remain quiescent for weeks

after molting. This is especially apt to be the case in the fall, when they are sluggish.

Most of the larvæ observed during 1912 molted twice. A few were seen to molt once, although it is possible that a molt might have been overlooked in a few instances. In the case of a few others it was thought that a third molt was seen, but this is doubtful. From this it is impossible to give even the approximate number of molts with any degree of accuracy, but present indications are that they molt at least five or six times.

The Pupa.

PUPATION.

In about July or August the mature larvæ become shorter, and while they are not more constricted between the segments, they have the appearance of being so, as the segments swell slightly in the middle. At the same time there is a slight change in color, the entire larva appearing sickly and of a dirty yellow color. During this period the wireworms lose most of their activity, and whatever movements they make are slow and weak. When pupation is only a short time off they are quite helpless, and if their pupal cells are broken open they are unable to make new ones. Several which were taken in this condition were able to pupate safely, the operation taking place in a Janet ants'-nest cage.

THE PUPAL CELL.

The pupal cell is simply an enlargement at the end of the larval channel, and is slightly elliptical in shape. It is unlined but is quite smooth and the soil is well compacted. The depth of the pupal cell below the surface varies between 4½ and 9 inches, but most of those observed were at a depth of about 6 inches. It is apparent that the wireworms move very little preparatory to pupating, as pupæ are often dug up with the wireworms close to the old beet roots.

SOIL CONDITIONS AFFECTING PUPATION.

The pupæ (Pl. V) are unaffected by a little dryness, but if the soil becomes quite dry for a long period they do not emerge. Many healthy pupæ were dug up in the field in soil which contained only a little moisture. Those which came through best under laboratory conditions were from cages where the soil was kept only moderately damp. Where the soil was too wet a large percentage of the pupæ sickened and died. Those found dead under these conditions were attacked either by a fungus or a bacterium, or sometimes by both. It was not determined whether these organisms were parasitic or sapro-

phytic. An attempt was made to rear some of the pupæ in the plaster-of-Paris cages, but the cages seemed to be too damp, and all the pupæ died. These appeared like those killed in the flooded cages, and the same bacterium and fungus infested them.

VITALITY OF THE PUPA.

The pupal stage is the most unprotected state in the life cycle of this insect, and is the one wherein the insect is most liable to mechanical injury. A small percentage of the pupæ dug up out of doors were injured when their pupal cells were broken open, and consequently died. On the whole, however, the pupa is not nearly so susceptible to injury as is the popular belief. Such pupæ as were unearthed in the field were kept under artificial conditions and handled quite roughly and often, yet most of them produced adults. The two pupæ which were photographed for this bulletin (see Pl. V) were handled several times with forceps, were exposed on a glass plate to light and temperature for hours, and on one occasion were dropped from the table to a chair, a distance of about 10 inches. In spite of this treatment both produced normal adults, and when last observed, October 14, 1912, were alive. There were several similar cases in which the results were the same as in the example cited. The pupæ are quite helpless and are unable to make new pupal cells in case the old ones are destroyed. For this reason, probably, a large percentage of those disturbed in the field die from exposure. The pupæ are sensitive to light, heat, and contact, and when disturbed move their abdomens in such a way that the tip describes a circle. As the pupa becomes older it becomes more deeply colored and more sensitive and active.

CHANGES IN COLOR OF THE PUPA.

The first signs of coloration of the pupa are the eyes, and these appear as dusky bluish spots. The abdomen and thorax then become slightly yellow and the mouthparts and wing covers very faintly dusky. The tip of the abdomen remains whitish. About a week before emergence the entire pupa becomes darker, and just a few days before emergence the wing covers and mouthparts are quite dusky and the eyes assume a dusky color, the mouthparts, eyes, and wing covers remaining a little the darkest and being quite conspicuous.

LENGTH OF THE PUPAL STAGE.

The length of the pupal stage under laboratory conditions varied from 25 to 36 days, with most of the adults emerging in about 26 to 32 days. These were kept as nearly as possible under conditions which would compare favorably with field conditions. This gives, roughly, a period of a month for the pupal state.

The Adult.

EMERGENCE OF THE ADULT.

During the last few days before emergence the pupa becomes very sensitive to light or contact, and when disturbed turns around in its pupal cell by moving its abdomen. An attempt was made to photograph one during this state, but in the hour and a half it was exposed it did not remain quiet long enough for an exposure to be made. The abdomen is drawn in and out as if the beetle were trying to break the pupal skin. This goes on for some time, often for more than a day, and finally the pupal skin splits down the dorsum of the thorax and is worked off. The beetle (Pl. XVI), which has been quite active in shedding its skin, now becomes quiescent, and folding its legs and antennæ as they were in the pupa, remains in the pupal cell. The cast pupal skin lies in the posterior end of the pupal cell along with the last larval skin, and helps form an obstruction between the pupal cell and the old larval channel. The cast pupal skin is semitranslucent white and thin, but at the same time quite tough.

In two cases the legs of the beetle broke through the leg cases before the pupal integument split down the dorsum. Neither of these adults completely emerged, and after moving their legs feebly for a few days they died.

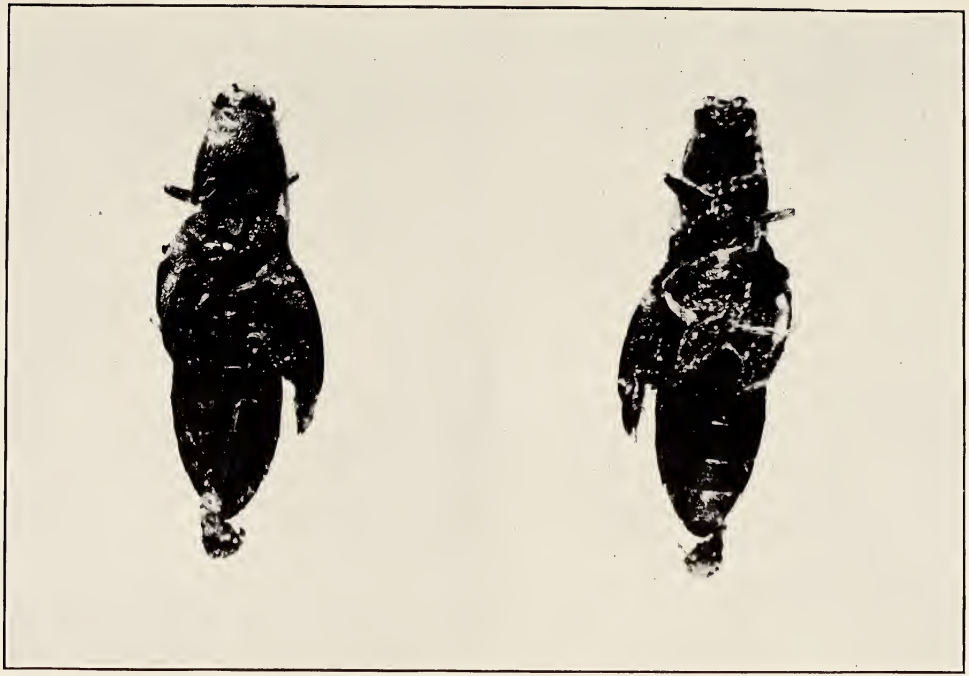
PERIOD OF EMERGENCE.

The period of emergence of the beetle from the pupa varies widely. This was true both of those which were reared in the laboratory and of those pupæ which were collected outdoors. Adults emerged between early August and October in the laboratory, and pupæ from the fields have given adults between the same dates. One pupa from the field transformed to adult October 6. Mr. Russell observed one adult emerge in the laboratory as late as October 17.

Beetles disturbed during the fall are able to bury themselves and live if they are not injured. Several which emerged in the laboratory were constantly disturbed so they could be watched, but it seemed to have no ill effects on them.

ACTIONS DIRECTLY AFTER EMERGENCE.

As soon as the pupal skin is shed the adult, retaining the position it had held as a pupa, lies in the pupal cell. At first the beetle is a little softer and lighter in color, but soon becomes hard and fully colored. Since none of the pubescence on its thorax or elytra has been rubbed off, it appears grayish in color. At this time these beetles are totally different in their actions than they are in the spring, when they appear on the surface, being negatively heliotropic and hiding under anything they can find or burrowing into the soil when exposed to light. They also seek damp, cool quarters in



ADULT OF THE SUGAR-BEET WIREWORM (LIMONIUS CALIFORNICUS) ISSUING FROM THE PUPAL SKIN. DORSAL VIEW AT LEFT; VENTRAL VIEW AT RIGHT. ENLARGED. (ORIGINAL.)

FIG. 1.—BEETLES OF THE SUGAR-BEET WIREWORM (LIMONIUS CALIFORNICUS) IN SECONDARY HIBERNATION UNDER SLICE OF SUGAR BEET. (ORIGINAL.)

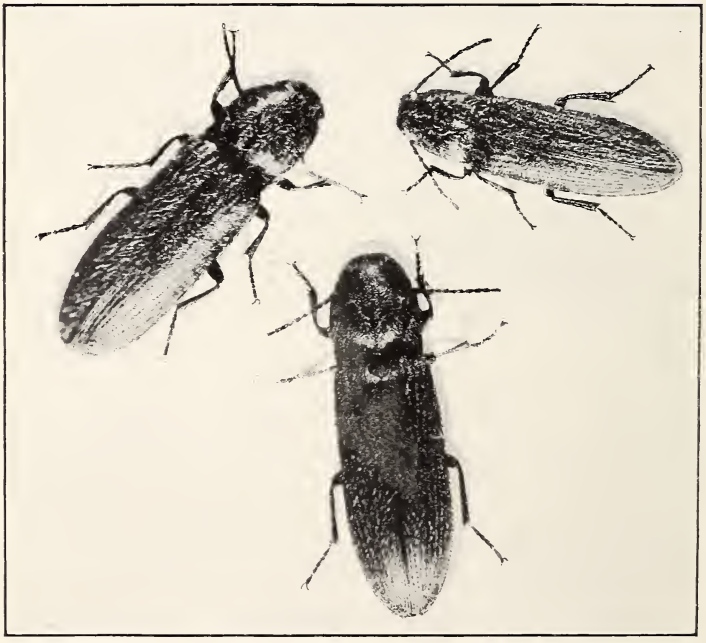


FIG. 2.—BEETLES OF THE SUGAR-BEET WIREWORM PHOTOGRAPHED WHILE FEEDING ON SLICES OF SUGAR BEET. (ORIGINAL.)

HABITS OF THE BEETLES OF THE SUGAR-BEET WIREWORM (LIMONIUS CALIFORNICUS)

preference to the dry, warmer ones. The habit of feigning death, so marked in the spring when they appear, is totally lacking at this time, and about the only way to make them move is to touch them.

When they are dug up from their pupal cells, or from the ground in which they have been hiding, they become active in a short time, look for another hiding place, and as soon as they find it draw in their legs and antennæ and resume hibernation. They are very sluggish, move slowly, and do not attempt flight.

APPEARANCE OF BEETLES IN THE SPRING.

In the early spring, during a period which covers two months, the beetles dig out of their cells, appear at the surface of the ground, and become partially active. That the time of this "emergence" is governed by several factors is strongly suggested by the diversity in the time of appearance. The average mean temperature is probably the main factor, but such causes as the kind and porosity of the soil in which they have pupated, and the rains, certainly help in determining the time of their appearance. This latter point was suggested by the fact that beetles were always more abundant in the fields following a rain than they were directly preceding it. This might be explained by the fact that their cells became too wet and they had to dig out for safety.

Just after their appearance in the spring the beetles are very sluggish and collect under rubbish of all kinds in the field. They still appear to be in a state of semihibernation and none are ever noted sunning themselves, feeding, or moving about. When their shelters are removed they are found in the same position they maintain during hibernation, with their legs and antennæ folded closely against their bodies. When the sunlight strikes them they slowly become active and search for another hiding place. In every respect their condition at this time resembles hibernation, except that they more quickly become active. To distinguish between this condition and their true hibernation in the soil, the former for want of a better word was called "secondary hibernation." This period lasted from about the middle of February, or a little earlier, till the middle of March. It is little more than a transition period between their hibernation and their period of activity. During this time the weather was quite cold, with cloudiness and showers at intervals.

BEGINNING OF THE PERIOD OF ACTIVITY.

The beetles are so slow to show signs of activity and so sluggish during the earlier part of their active period that no hard and fast line can be drawn between the latter and their so-called secondary hibernation. Furthermore, under every beet active and inactive

beetles may be found side by side. Now and then, about the middle or latter part of April, a beetle is seen sunning itself at the edge of a beet under which it had been hiding. At about this time, also, it was noted that the underside of many of the beets which sheltered beetles was roughened and had the appearance of being shredded. At first no attention was paid to this until by chance a beetle was noted feeding on an old beet, and then it was seen that the roughened places on the beet were the feeding marks of the adults. Whenever a beet was turned over the beetles were for the most part active (Pl. XVII, fig. 2), but a few were still in their secondary hibernation (Pl. XVII, fig. 1). The feeding marks on the beets become more and more noticeable but are never especially extensive, as the adults at the period of their greatest activity are light feeders.

Even at this time the beetles are not entirely normal in their actions. This is most noticeable in regard to the habit of feigning death, so characteristic of most of the elaterids. When a group is exposed by removing the beet under which they have been hiding, at least half of them move about searching for shelter. This is probably due to the fact that their senses are not very acute at this time, and they consider only shelter. About a month later, however, when a group of beetles is exposed by removing the beet shelter, most of them remain quiet for some time, even though they may happen to be in an unusual position.

VARIATION IN THE SIZE OF BEETLES.

Among the beetles taken in the field there was a very noticeable variation in size. (See Pl. I.) The length was often found to vary between 9 and 12.2 mm., and the width between 2.5 and 3.5 mm. The larger ones outnumbered the smaller ones almost 2 to 1, since about 15,000 of those collected could be referred to the larger size to about 9,000 of the smaller, while about 2,000 or 3,000 were so nearly on the dividing line between the other two sizes that they were unclassified. At first the large ones were thought to be females and the small ones males, so it was concluded that the females outnumbered the males about 2 to 1. Such did not prove to be entirely the case, for when copulation became general some of the small ones proved to be females, and not a few of the larger ones were seen to be males. Everything considered, it seems that sex is quite independent of size, for the males and females were seen to occur in about equal numbers.

VARIATION IN THE COLOR OF BEETLES.

From the outset it was noted that there was great variation in the color of the beetles. This difference was most noticeable on the elytra, which varied from light buff to deep brown or dusky black.

There seemed to be a rather plain dividing line between those with the buff wing covers and those with the brown ones, so they were separated. About 1,500 or 2,000 could be referred to the former class. Some of these were sent to Dr. Chittenden for determination, and concerning them he wrote as follows:

No. 495 (?) is *Limonius* sp. near *californicus*. It does not appear to agree perfectly with the *californicus* with which I have compared it, and is not represented in our duplicate collection.

The relationship of these beetles will be worked out in the future.

The true adults of *Limonius californicus* also varied considerably in color, as some were found which were a relatively light brown. These color variations occurred in all sizes and both sexes, so color seems to have no bearing on the sex of the adult.

FEEDING OF THE ADULTS, AND FOOD PLANTS.

When the beetles were first collected the character of their food was unknown, and in an endeavor to find their natural food all the different kinds of foliage found in the beet fields were tried, but without success. Adults by the hundreds were placed in cages containing tender young beet plants, and while they climbed all over the plants they were never seen to feed on them, nor could any feeding marks be found on the plants. A close watch was kept on the adults collected in the field, and at last, as has been stated before, they were noted feeding on the old left-over beet roots, now half dried and partially rotten. When these were substituted for the beet foliage in cages, feeding was begun at once. A few instances were noted where the adults had eaten into the roots to such an extent that the head and thorax were hidden. Such cases, however, were rather exceptional, and the beetles may be considered as light feeders. In addition to this, their feeding, from an economic point of view, may be disregarded.

The adult has been noted feeding on the following substances:

Old beet roots.
Alfalfa roots (*Medicago* sp.).
Johnson-grass roots (*Sorghum halepense*).
Wild beet roots (*Beta* sp.).
Young beet roots.

The old beet roots are the favorite food, and it is only occasionally that beetles are noted feeding on the other substances listed.

The beetles seem to be able to locate food readily and at quite a distance. In the laboratory whenever a slice of beet was placed in the cages the adults would be clustered about it in a very short time.

In the field the beetles were always found at the old beets and always occurred in the greatest numbers where the beets were most plentiful.

In one field, which had a great many old beets on the surface, the beetles were taken from under almost every one, and sometimes in large numbers. It was a common matter to find from 30 to 70 adults under single beets, and as many as 243 have been found hiding under one beet. Another favorite shelter was afforded by the old beet tops (Pl. XVIII) left in the field from the previous year's harvest.

In the field which adjoined this one there were few or no old beet tops and beets for shelter, and here beetles were rarities. This field, just the year before, suffered more than any of the surrounding fields from wireworm injury, so there must have been beetles which developed from the mature wireworms that had caused the damage. In other fields, however, which had suffered similar injury but in which the old beets had been allowed to remain, beetles were present in large numbers. There seems to be only one explanation for this fact, and that is that the adults had emerged from the cleaned fields and, not finding any shelter, had been obliged to move to other fields or be destroyed by the birds. This was further indicated by the fact that all the beetles found in the clean fields were moving about. The state of affairs was found to be the same in other fields aggregating over 600 acres, where the conditions were similar.

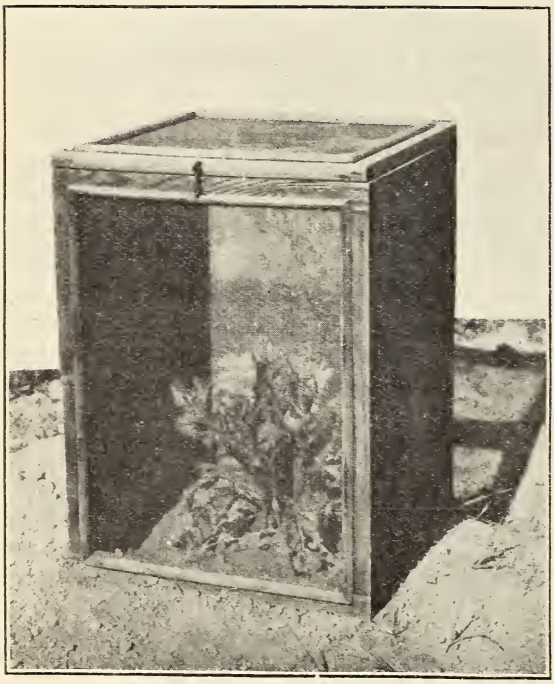


FIG. 8.—Screen cage used in observing oviposition of adults of the sugar-beet wireworm under field conditions. (Original.)

STYLES OF REARING CAGES USED.

Several styles of rearing cages were used, but only a few will be considered. The ones used indoors consisted of battery jars, flowerpots, and flowerpots with lantern globes. The highest death rate was found in the first, because there was no drainage and the contents

SECONDARY HIBERNATION OF THE SUGAR-BEET WIREWORM (LIMONIUS CALIFORNICUS). BEET TOPS USED BY BEETLES AS QUARTERS FOR SECONDARY HIBERNATION. (ORIGINAL.)

tended to become foul. The two types last mentioned were about equal in efficiency, but the main difficulty lay in the fact that they were small and it was easy to overcrowd them.

The cage used most successfully was a large screen cage of the common type, kept outdoors. (See fig. 8.) Within the cage were several flowerpots, buried to the level of the ground, each containing young beet plants. The soil in the pots was kept loose and damp, and the soil around the flowerpots was tamped hard. This cage was large, well ventilated, and gave the beetles plenty of room in which to fly about. Its best feature lay in the fact that the beetles all deposited their eggs in the flowerpots, since this was the only place where they could bury themselves easily. It this way the eggs were concentrated much more than they would have been under natural circumstances. As soon as one flowerpot contained a great many eggs it could be removed and another substituted. This cage also gave natural conditions, as the soil it contained was just as damp as that in the field, and since the cage was placed in the sun and was so airy the beetles were always kept at the field temperature. The death rate was very much lower in this cage than in any of the others and there were live adults in it for some time after all had disappeared in the other cages.

DURATION OF LIFE UNDER VARYING CONDITIONS.

To test the duration of life under varying conditions some adults were placed in various styles of cages and others were kept under various conditions as concerned the food and water supply. Some were kept without either food or water, some with food but without water, and some with water but without food. In every instance the beetles lived much longer than was expected of them and proved that they are not only quite hardy but can get along on little food.

One hundred and forty adults were placed in dry battery jars without food or water, and the jars were closed with gauze. The results were as follows:

Eighty-two adults died in from 9 to 12 days.
Forty adults died in from 12 to 14 days.
Eleven adults died in from 14 to 16 days.
Five adults died in from 16 to 18 days.
One adult lived 20 days.
One adult lived 22 days.

None of the beetles was very active after the twelfth day. These conditions were much more severe than any that they might encounter under field conditions.

The adults kept with water but without food were also kept in battery jars. These jars contained about 3 inches of soil, and this

soil was kept quite damp by additions of water from time to time. This cage presented very much the condition which would hold in the field if all the food could be eliminated. Five hundred and sixty beetles were used in this experiment, with the following results:

About 60 died before 10 days.
About 100 died before 10–15 days.
About 200 died before 15–18 days.
About 100 died before 18–22 days.
About 60 died before 22–25 days.
About 30 died before 25–28 days.
About 6 died before 28–30 days.
About 2 died before 30–31 days.
About 1 lived for 34 days.
One lived for 40 days.

The last 10 to die were females. Their abdomens were quite swollen, but they did not lay any eggs—at least none could be found—and when they were dissected after death the ovaries, while containing some eggs almost mature, were quite shrunken and dry. None of the beetles was very active after 15 days, and after 25 days they were very feeble, the last few to die being unable to walk during the last days they lived.

Many adults were separated and kept in vials and given food but no water. Care was exercised to have this food as dry as possible. Out of 78 used in this experiment only 12 died during the first 15 days, and the remainder were quite active. It was so difficult to obtain the food dry enough to affect them that the experiment was discontinued.

LENGTH OF TIME ADULTS CAN BE SUBMERGED.

Several adults were submerged in water in a tube and kept below the surface by a smaller tube placed within the first one. The water was perfectly clear and care was taken to remove all the air. At the end of 15 minutes the beetles had ceased to move and at the end of 20 minutes they were removed. They seemed dead, but within a few minutes were moving about actively and seemed none the worse for their treatment.

Another lot was submerged for 40 minutes and within a half hour after being taken out were as active as ever. The tests were not carried further, as these were considered as severe as any they would be subjected to under field conditions. Twenty adults were floated on water for 15 hours and at the end of that time only three were dead. From these results it was concluded that a majority of the beetles could survive a severe storm.

EFFECT OF TEMPERATURE ON THE ADULTS.

The adults of many of the eastern species have been reported by some observers as being primarily nocturnal in habits.[1] Other observers record them as flying readily both by day and night. The adults of *Limonius californicus* seem without exception to be warm-weather insects. They not only attain their greatest activity during the middle of the day when the heat and light are at the maximum, but during the morning and evening hours they are sluggish and quiet. Some specimens were kept in the writer's room during their entire life and none was ever observed feeding or copulating at night. On the warmest nights a very few were observed moving about sluggishly, but their activity at this time can not be compared to that which occurred during the daytime and especially when the temperature was over 75° F.

Several experiments were conducted for determining the direct relation between temperature and activity. The apparatus used was very similar to that used in the boll weevil investigations,[2] except that instead of the outer tube a flask was used, as it was believed that this would afford more even heating.

The results agreed quite closely with those recorded in Bulletin No. 51 (pp. 101–102) and an approximation is given below:

48° F. Beetles quiescent.
54° F. Few crawling about sluggishly.
60° F. Beetles all moving about.
70° F. Beetles becoming active.
75° F. More active, few flying.
80° F. Many flying.
85°–90° F. All flying, very active, seem greatly excited.
93°–94° F. Period of greatest activity.
97° F. Few becoming quieter. Seem to be suffering.
99° F. Many becoming quieter.

This experiment was varied slightly by placing damp filter paper in the inner tube so that the heat would not be so dry. The new results did not differ very startlingly from the preceding, except that the beetles did not seem to suffer so much at the higher temperature and seemed less excited.

Under field conditions 75° to 80° F. seems to be the optimum temperature for their various activities. At 70° F. they are quite active, but few are noted in flight, especially if there is a moderate wind blowing. At 60° F. very few are noted moving in the fields, and these are generally close around the beets under which they have been hiding. The beetles are always more active on bright days than on darker days, even if the temperature is the same. This

[1] Comstock and Slingerland, Bul. 33, Cornell Agr. Exp. Sta., 1891.
[2] Bul. 51, Bur. Ent., U. S. Dept. Agr., Pl. XVI, fig. 72, 1905.

difference in their actions caused by light was very noticeable when cages were removed from the insectary and placed in the sunlight. The beetles would fly about at once and before long many pairs could be taken in copulation. When the cages were replaced in the insectary activity would cease as suddenly as it had begun.

ABILITY OF THE ADULTS TO WITHSTAND UNFAVORABLE CONDITIONS.

The adults showed remarkable ability to withstand shocks of various kinds, whether occasioned by physical injury or by sudden and unfavorable climatic conditions.

A few cases noted in the field will show their ability to withstand physical injury. When beetles were collected in the fields individuals were noted on several occasions to have been injured by their predaceous enemies, *Calosoma cancellatum* Esch. and *C. semilæve* Lec., and these were separated from the others so they could be watched. Those which had merely lost some of their legs did not seem to be in the least inconvenienced. Others which were quite severely injured managed to survive as long as most of the other beetles. One, which had its abdomen so nearly severed near the anterior end that it had lost one of its elytra, lived for several days.

As to their ability to withstand unfavorable weather conditions, it may be stated that while over 25,000 beetles were collected from the field in a period which exceeded a month, very few were found dead. During this period there were sudden and great changes in temperature and several severe rainstorms.

In view of the fact that the beetles seem to be so hardy in the field, it is difficult to explain the heavy death rate which was noted in all the cages about the time of oviposition. It seems that they must lose much of their vitality during their later life, so that by the time oviposition is about to take place they are comparatively weak.

METHOD AND TIME OF MATING.

When once the adults have attained their normal activity they mate readily during the warmer hours of mild days. Beetles were taken mating as early as March 17, 1912, and as late as April 23, 1912. Every pair taken in copulation in the field was taken between 9.30 a. m. and 3 p. m. No pairs were ever found in copulation if there was a strong wind blowing or if the sky was cloudy or the weather cold and rough. The mated pairs were generally found near or beneath the beets under which they had been hiding and feeding, though one pair was found in a crack in the soil, about 2 inches below the surface.

Temperature has a very direct effect on copulation, as was proved by the laboratory experiments. Battery-jar cages, when taken from

the cold rooms, contained only semidormant beetles, but after being placed in the sun for a time the beetles very soon became active and copulation took place. When the cages were returned to the cold rooms it was only a few moments until copulation ceased and the beetles became sluggish again.

The method of mating of these beetles seems to be more or less unique. The male shows no signs of excitement until he comes in contact with the female, and then he rapidly attempts copulation. After the male has assumed his position he throws himself over backward so that he is on his back with his body in the same line with that of the female, but pointing in the opposite direction. The male then folds his legs and antennæ close against his body and remains quiescent during the operation. If disturbed the female seeks shelter, walking slowly and dragging the male after her. The duration of the process varied greatly in the cases noted, covering from 7 to 19 minutes. After the operation the male was generally noted to be much more active than the female, but was not seen to attempt copulation a second time, even where the pair were confined in a small vial for some hours.

Much of the copulation attempted in the cages was unsuccessful, about nine attempts out of every ten coming under this head. Whenever several males were attempting copulation with the same female at the same time they were noted to fight one another.

About April 1, 1912, the abdomens of the females began to swell noticeably and a close watch was kept for the eggs. Every day about six females were dissected so that the development of the eggs could be watched. The immature eggs were small and disk-shaped, being little more than half as large as the mature eggs. They appeared as opaque spots in the translucent jellylike ovaries, which filled quite completely the ventral portion of the abdomen. The development of the eggs was relatively slow, the greatest change appearing in the ovaries, which increased rapidly in size until at the time of oviposition they practically filled the abdomen.

ACTIONS OF THE ADULTS AFTER MATING.

During the last week before oviposition the females spent all their time burrowing under the soil, and were never noted feeding or on the surface. Whenever they were dug up they immediately buried themselves again. If the ground was not allowed to dry out too much the females remained active and healthy, but in several cells in which the soil completely dried out the females died.

The males did nothing but feed and crawl about on the surface. They lived, on the average, from two to four weeks after mating, so it seems possible that one male might fertilize more than one female.

In one instance, when the female in a cell had been dug up she came in contact with the male. The latter attempted copulation, but unsuccessfully.

OVIPOSITION.

On April 9, 1912, the first eggs were deposited. These were laid in a vial which contained several females in which the development of the eggs was more advanced. These eggs were scattered throughout the soil.

In only one instance was a female noted in oviposition, and that was under unnatural circumstances. Several gravid females had been placed in a glass, on the bottom of which was about half an inch of very compact soil. This glass was placed in the dark room for several hours, and when observed again one female was attempting oviposition between the soil and the glass. The beetle thrust her ovipositor down several times, and finally the egg was placed in the bottom of the hole made by the ovipositor. The ovipositor was then withdrawn slowly and then thrust back part way several times as if the beetle were trying to cover the egg. The entire operation took but a very short time.

When the soil in the cages was broken up and examined for eggs it was seen that oviposition under natural conditions must be quite similar to that observed, as eggs were found at intervals under the channel made by the digging female.

By the latter part of May the females became very scarce, as they live but a short time after laying their eggs. The males for the greater part died during about the middle of the period of oviposition.

Approximate Length of the Life Cycle.

Considering the length of the egg stage as one month and the length of the pupal stage as the same, these, added to the length of the life of the adult, will give from five to eight months. If, as has been stated before, the larval stage lasts for over three years, it is seen that the length of the life cycle from egg to egg would be four years.

SEASONAL HISTORY.

Beetles from Emergence to Hibernation.

The life of the adult, from emergence, through hibernation, until their appearance after hibernation, is governed to a great extent by conditions over which the beetles themselves have no control. The greater part of the beetles emerge from the pupæ about the middle of September. The beets are plowed up for the most part during September and October, so the insect is in danger of being disturbed either during the pupal stage or soon after it has changed to the

adult. The plowing which the land receives at this time can hardly be called a plowing, but the ground is torn up to a depth of from 6 to 12 inches. As the soil is dry, that disturbed is for the most part in large clods, so there is little chance that many pupæ or adults will be disturbed.

Those which by chance are disturbed are either killed outright or have to live under changed conditions until spring. If they happen to be pupæ the chances must be very much against them, and they will probably either be injured by the sharp particles of dirt or will dry out. If the insects are in the adult stage they will have a better chance of survival, but here also they may be compacted into the soil and killed, or be eaten by birds, since, living under unnatural conditions, they are obliged to appear earlier in the spring than they would otherwise. Even when kept under laboratory conditions many of those disturbed in the fall can not live till the normal time of their appearance.

Hibernation.

The adults pass the severest part of the winter in the soil. If disturbed they winter in their pupal cells, where they are well protected, as these are on the average about 6 inches below the surface. This tempers the winter for them very well, and moisture can reach them only after heavy rains, and these seldom if ever occur except at the latter part of the hibernating period. When the beetles are disturbed in the fall they dig down into the soil for shelter. The depth to which they go varies. In some cases, where the soil is powdery, they go down only about from $1\frac{1}{2}$ to 3 inches, but when the soil is partially made up of clods and full of cracks they are sometimes found from 4 to 6 inches below the surface.

Mortality During Hibernation.

Under ordinary circumstances and where the pupal cells are undisturbed, a large percentage of the beetles emerge safely—at least this is so under laboratory conditions. One cage was watered and kept outdoors so that the beetles were subjected to conditions as severe as the ordinary field conditions, yet all came through safely. Of those disturbed in the fall, not enough have been tested to give representative figures, but thus far almost a third of those treated in this way have died during hibernation.

Gradual Emergence from Hibernation.

The time of the appearance of the beetles in the spring is influenced to a large extent by artificial agencies, the most important of which is spring plowing. This plowing, which takes place as soon as possible

after the first rains, is quite thorough, averaging from 10 to 14 inches deep, and as the soil is damp and mellow at this time very few clods are left. This treatment disturbs most of the beetles, and these, unless the weather is too severe, may come to the surface and finish their hibernation in any sheltered place they can find. If the weather is severe and cold many of the beetles prefer to remain in the soil. It is due to these conditions that there is a variation in the time of appearance of the adults, as has been proven by systematic collection in the fields.

Collections were made in some of the fields day after day and tabulated. The beets which sheltered adults every day were marked, and the beetles which were collected from them every day were noted. The following table gives the number of beetles which were taken from under the same beet on the dates given:

TABLE I.—*Emergence of adults of the sugar-beet wireworm from hibernation in the field.*

Date.	Number of beetles.	Date.	Number of beetles.
Feb. 29	2	Mar. 12	4
Mar. 1	1	Mar. 13	7
Mar. 2	7	Mar. 14	1
Mar. 3	3	Mar. 15	3
Mar. 4	17	Mar. 16	86
Mar. 5	2	Mar. 17	11
Mar. 6	1	Mar. 18	0
Mar. 7	1	Mar. 19	2
Mar. 8	0	Mar. 23	1
Mar. 9	29	Mar. 24	36
Mar. 10	47	Mar. 26	9
Mar. 11	13		

As these notes were taken before the beetles were moving through the field very generally, it appears that the latter must have come from the soil near the beets which were used for hibernating quarters.

SECONDARY HIBERNATION.

The beetles which are driven to the surface prematurely seek what may be termed "secondary hibernation" under almost any shelter which can be found. The substances in the following list, under which beetles were found, are named in about the order of preference:

(1) Left-over beets.
(2) Old beet tops.
(3) Wild beet roots.
(4) Alfalfa roots.
(5) Johnson grass roots (*Sorghum halepense*).
(6) Lambsquarters (*Chenopodium* sp.).
(7) Pigweed stalks (*Amaranthus retroflexus*).
(8) Wood.
(9) Clods.
(10) Cracks in soil.
(11) Old sacks.
(12) Manure.
(13) Miscellaneous rubbish.

Items 8 and 9 (wood and clods) sheltered practically all the beetles. The last-named item included paraffin roofing, old bottles, pottery, etc. The wide diversity of this list shows that the beetles are not very particular about the character of their shelter.

It is interesting at this time to note that no beetles were taken from under charred beets or wood ashes. This point was well illustrated in the corner of one of the fields which proved to be the choicest collecting ground. It happened that in this place a large amount of rubbish had been burned the previous year, and about half the old beets lying about on the ground were charred. Adults were taken in numbers from this corner daily, but not one was ever found under the beets which were charred. The same thing was true of the wood ashes.

The numbers of beetles taken from single beets were much larger than might have been expected. As has been stated before, as many as 243 have been taken from under a single beet, and on one occasion 187 were taken from under a single beet top which was less than 3 inches in diameter. The concave top was entirely filled with the beetles, which in some places were piled from 2 to 4 deep.

Occurrence of Beetles in the Field.

Up to the middle of March the adults are found close to their hibernating quarters, either feeding or sunning themselves. At about this time, however, there is a general dispersal of beetles, and their collection becomes a difficult matter. Flight is of common occurrence, as is copulation. The writer watched many beetles which were moving about the fields, to see what they were doing, but to all appearances they did nothing except wander about. Some were watched to see if they would oviposit, but nothing of this kind was noted.[1] To judge from their actions in the laboratory cages, these adults were moving about preparatory to burrowing into the soil for oviposition.

Effect of Food in the Field on Dissemination.

In the latter part of their secondary hibernation, and before they scatter through the fields, their presence depends very much on two factors, namely, food and hibernating quarters. Once they begin moving they feed very little, and food seems to have no effect on the direction or amount of their movement.

As this is, economically, the critical point in the life of the adults—since where they collect, the eggs will be laid—they were watched carefully to see if there were any factors which governed their dispersal through the fields. The amount of food and the size of the

[1] Subsequent rearing work in the laboratory proved that this was quite too early for oviposition.

young growing beets were carefully taken into consideration, but the significance of these points, if there is any, is too slight to be noticeable. While the beetles have quite a strong flight, it was observed that they stay relatively near their hibernating places, so the most important factors at this period are the food and hibernating quarters which determined their presence earlier. These conclusions were arrived at from observations in fields aggregating several hundred acres. These factors, however, govern dissemination under normal conditions only.

Other Factors Governing Dissemination.

One factor which governs the direction of flight of the adults to some extent is the wind. This factor, however, has its limitations, as the beetles can fly with ease against a very light breeze, and if the wind is blowing too strongly they do not fly at all.

The floods which are apt to occur during the time the beetles are in secondary hibernation, or a little later, are probably of some importance—at least they must be so locally, where the San Gabriel River spreads over many acres of the beet fields almost every year. This river flows slowly and carries much rubbish, so that a large percentage of the beetles carried along would probably survive.

NATURAL CONTROL.

Enemies and Checks to the Beetles.

The adults of *Limonius californicus*, being slow in their movements and conspicuous, are quite subject to the attacks of predaceous enemies. The good work of these enemies is further helped by the fact that the fields are quite bare at the time they are present in the largest numbers, while the beetles are concentrated for a part of the time.

Unfortunately no figures can be given regarding the relations between the birds of the beet fields and the beetles, but a few observed facts may be given at this time. The only notes which bear on the insectivorous habits of the birds locally were taken on examination of the excrement of the California shrike (*Lanius ludovicianus gambeli*) during the month of April. This excrement was made up almost entirely of coleopterous wing covers, and of these *Limonius californicus* and *Blapstinus* sp. formed about 90 to 95 per cent. A very reasonable estimate would be that at least 70 to 80 per cent of the excrement examined was composed of fragments of *Limonius californicus*.

Many observers have determined the fact that nearly all insectivorous birds eat different species of Elateridæ readily, as the latter do not seem to be in the least distasteful to them. Following is a partial

list of the birds occurring in the beet fields, which have been proven to be insectivorous.[1] Those marked (*) were especially abundant:

Killdeer (*Oxyechus vociferus*).
* Valley quail (*Lophortyx californicus vallicola*).
Western nighthawk (*Chordeiles virginianus henryi*).
Ash-throated flycatcher (*Myiarchus cinerascens cinerascens*).
* Western meadowlark (*Sturnella neglecta*).[2]
* Brewer's blackbird (*Euphagus cyanocephalus*).
* Native sparrow.
* California shrike (*Lanius ludovicianus gambeli*).

Next to the birds as insect destroyers can be ranked the predaceous beetles belonging to the family Carabidæ, or ground beetles. Only two were noted, *Calosoma cancellatum* Esch. and *C. semilæve* Lec., but these proved to be important factors in the control of the beetles. Both of these occurred commonly throughout southern California. Sometimes as many as 15 to 20 would be noted in a single collecting trip. *Calosoma cancellatum* occurred in the greater numbers.

These predatory enemies are able to dispose of a large number of adults daily, as many outdoor observations proved. In one instance the examination of a large beet gave 31 live elaterids, 1 *C. cancellatum*, and the remains of 117 elaterids. This beet had been examined just two days previously, so this represented not more than two days' work. The rapidity of the work may be judged from the fact that the remains of a dozen of the elaterids were still moving their legs feebly when discovered.

The carabids in feeding never touch the head or thorax, but bite off all or a part of the abdomen. As the abdomen, except when filled with eggs, contains little food it is readily understood how these ground beetles are able to destroy so many elaterids a day. The carabids did most of their feeding while the elaterids were in their secondary hibernation or early feeding period. They were especially valuable at this time, as they could dig under the beets and destroy the beetles collected there.

These predaceous enemies—carabid beetles and birds—make a very good combination, as the beetles are an effective check early in the season, and later, when the elaterids are moving through the fields, the birds are at their best.

Sudden and very severe storms probably act as further checks, but in a mild year, such as 1912, very few beetles were found to have been killed in the field. The adults are also attacked by a fungous disease. This disease works well under laboratory conditions, but less

[1] See Senate Document No. 305, 62d Congress, 2d Session, p. 14, 1912.

[2] Mr. Bryant, in the Pomona Journal of Entomology, vol. 4, No. 3, speaking of the western meadowlark, says, "Ground beetles are taken each month of the year." He then names *Limonius californicus* among those taken.

than 0.1 per cent were affected by it in the field. These two checks are of very little importance.

Enemies and Checks to the Larvæ.

Two characteristics of the wireworms, their thick skins and their underground life, cause them to be almost free from enemies. Of the 10,000 larvæ collected not one was noticed which was attacked by an internal parasite, although such parasites have been reported attacking Elateridæ. Curtis [1] reports an ichneumon parasite on wireworms in Great Britain, and says that Bierkander (of Sweden) also found them. Dr. S. A. Forbes [2] reports a single instance where a parasitic fly was reared from a wireworm. Very probably there are no efficient parasites in this group.

The sugar-beet wireworm is, however, eaten readily by several kinds of birds whenever exposed. During the spring, when several of the fields at Dominguez, Cal. (6 miles from the ocean), were being plowed, it was noted that sea gulls (*Larus* sp.) were very abundant in the fields and followed the plow much as chickens do. They occurred by the hundreds and, as they are known to be omnivorous, they must have eaten numbers of wireworms. At this time and earlier crows were also very abundant in the beet fields. During this period the wireworms were feeding at the surface on the left-over beets, and it was easy for the crows to reach them. As crows are famed as wireworm destroyers it is only reasonable to suppose that they killed large numbers of the larvæ. This point will be investigated thoroughly in the future work on this insect.

Larvæ of a large carabid, probably *Calosoma cancellatum* Esch., have been found in the ground together with injured wireworms.

In addition to bird and insect enemies one fungous and two bacterial diseases have been noted on this wireworm. The fungus is only observed occasionally in the field, hence it is probably of little importance economically. The bacterial disease of the mature larva was especially disappointing, as it seemed to work only in certain cages. This naturally led to the belief that its presence was probably more the result of unfavorable conditions than the cause of them. The bacterial disease of the young larva did not promise much, as it did not seem to attack mature larvæ under any conditions.

As has been mentioned under the heading "Rearing cages used" (p. 21), many of the young wireworms which were kept in petri dishes died of a bacterial disease. This disease spread very rapidly, and there seemed no way to check it. Wherever it appeared, all the healthy wireworms were removed to a sterile cage and the infected cage sterilized. The cages were examined several times a day and all

[1] Farm Insects. By John Curtis, 1860, pp. 181. [2] 18th Rept. State Ent. Ill., pp. 47, 1891–92.

wireworms were removed just as soon as they showed traces of the disease. In spite of all these precautions the disease spread unchecked until, within 10 days of its appearance, it had killed every wireworm in the petri dishes, to the number of about 1,000.

The disease spread in the same way every time, and the wireworms killed by it were so characteristically colored that they could never be mistaken. When a larva became diseased, there was a very faint reddish coloration in the anterior portion of its body. When placed under the microscope, it looked as if the head and thoracic segment contained little, brilliant red, oil globules. The following day the specimen would be a deep blood-red all over its body and so putrid that when picked up on a pin point it would fall to pieces. The larvæ immediately surrounding it would show the faint red coloration and the following day they would be red and putrid, while the larvæ nearest them would be showing signs of infection. When the dishes were not sterilized, all the larvæ in a dish would be killed in from three to four days.

That the red bacterium was the cause of the trouble was very strongly suggested by the fact that whenever one infected wireworm was placed in a sterile cage the disease immediately made its appearance. This was further borne out by the fact that where a whole infected wireworm was used to make a culture on agar, a pure culture of the red bacterium almost invariably resulted. When the cultures were made on agar, the colonies showed in their true color—a beautiful rich blood-red. (See Pl. VIII, fig. 1, p. 20.)

It is interesting to note at this time that the mature wireworms which were exposed to infection by this bacterium were never affected by it.

Everything considered, the larvæ of *Limonius californicus* seem to be affected very little by their animal enemies and by their fungous and bacterial diseases, even when these latter are working under favorable conditions.

Fungi Affecting the Pupæ and Eggs.

A few pupæ in the laboratory were attacked by a fungus and presumably killed by it, as they died a short time afterward. As this occurred only in two cages and as no fungus-killed pupæ were found out of doors, it is probable that this infection only occurs under artificial conditions. Even if it did occur in the fields it would spread slowly, for during the time the insect is in the pupal stage the humidity is low and the soil in the fields is rather dry.

A fungus which attacked and killed some of the eggs of *Limonius californicus* in the rearing cages in the laboratory would probably seldom or never occur out of doors. Even if it did it would not be

of great economic importance, for when sound eggs were isolated in the cage in which the fungus was working they were seldom attacked, showing that the fungus must spread slowly. Its appearance was probably the result of unfavorable artificial conditions.

REMEDIAL MEASURES.

Historical.

Most of the literature thus far devoted to the study of wireworms from an economic standpoint has been a consideration of remedies. Probably no other insects have had more remedies tried for their control and with less success. Some of the remedies have been partially successful, but generally their cost has been such that their use for average crops is entirely impractical. One which would come under this head was a method tried on a small scale in Europe some time ago and consists in baiting the wireworms and collecting them.

Eleanor A. Ormerod,[1] studying several species, gave as remedies (1) compacting the ground, (2) clearing off vegetation, and (3) making applications of gas lime. She stated that crop rotation was of little value. John Curtis [2] suggested as remedies frequent plowing to turn up the larvæ, and applications of soot and lime. Mary Treat,[3] writing on these insects, suggested spring and fall plowing and the trapping of larvæ. Fall plowing as a remedy was recommended by C. M. Weed.[4]

The two most important sets of recommendations based on actual exhaustive experiments and careful study were those of Comstock and Slingerland [5] at Cornell and S. A. Forbes [6] in Illinois. Their recommendations are quite different, Forbes suggesting a careful rotation of crops, while Comstock and Slingerland advise fall plowing for the destruction of the pupæ and trapping the adults with poisoned bait.

Tests of Suggested Remedies Against the Sugar-Beet Wireworm.

In testing remedies for the sugar-beet wireworm only those were tried which heretofore had promised at least partial success and which were at the same time thoroughly practical.

ATTEMPTS TO DESTROY THE ADULTS WITH POISONED BAITS.

Experiments with poisoned bait were carried on against the adults, using the bait much after the method suggested by Comstock and

[1] Manual of Injurious Insects and Methods of Prevention. By E. A. Ormerod, 1890, pp. 109.
[2] Farm Insects. By John Curtis, 1860.
[3] Injurious Insects of Farm and Garden. By Mary Treat, 1882.
[4] Insects and Insecticides. By C. M. Weed, 1891.
[5] Bull. 33, Cornell Agr. Exp. Sta., 1891.
[6] 18th Rept. State Ent. Ill., 1891.

Slingerland.[1] These experiments from the first gave entirely negative results, as the beetles could not be induced to feed on any kind of foliage, either in the poison or check cages. Further experiments were carried on, using such substances as bran, shorts, alfalfa meal, and ground beet roots. The last bait was the only one which gave any promise, and this proved successful only under laboratory conditions. Where the poisoned bait was applied in the cages a few beetles were killed by it, but where it was tested in the field it gave negative results. This was probably on account of the light feeding habits of the adults and the abundance of food in the fields. The poisons used in the bait were Paris green, arsenite of zinc, arsenate of lead, and strychnine.

FALL PLOWING FOR DESTRUCTION OF THE PUPÆ.

The destruction of the pupæ by cultivation, while probably it has never been tested under field conditions, has been recommended by many students of this group because it is directed against the most helpless stage of the insect. From observations made of the results obtained by disturbing pupæ in the laboratory cages, there can be no doubt that this remedy would prove beneficial, since not only would it break open many cells and kill the pupæ mechanically, but it would also disturb the rest so that they would come out earlier in the spring and be subject to the attacks of their bird enemies. This fall plowing would have to be quite deep (9 to 10 inches), and very thorough, to be effective.

The main objection to this remedy is that three or four years must elapse before the benefits derived from it become apparent. One point will serve to illustrate this. It was reported through Mr. R. S. Vaile, the horticultural commissioner of Ventura County, Cal., that in one instance, in a field which had been fall-plowed, the wireworms were worse than in any of the surrounding fields. This was doubtless true, and would have been possible had the plowing killed every pupa. The wireworms which do the main damage for at least the next two years are already in the soil at the time of the plowing and are unaffected by it. This is true because the wireworms are not of sufficient size to be very injurious until the third year. Mr. Vaile states that it is a rule with many of the bean growers in his county to fall-plow their fields; and that any benefits which might have resulted from such a treatment have never been noticeable. He adds, however, that the thoroughness of this plowing might be improved upon in many cases.

[1] Bul. 33, Cornell Agr. Exp. Sta., 1891.

EXPERIMENTS WITH DETERRENTS AGAINST THE WIREWORMS.

A fairly exhaustive series of experiments was carried on, using repellent substances against the larvæ. While some of these experiments are a repetition of the work done by Comstock and Slingerland, the greater number are rather an addition to their work. From the start this work promised little, but was undertaken because, if successful, it would afford a remedy which would give immediate results, and this is most important with this insect.

A system was adopted regarding both the nature of the experiments and the times of application. Three tests were given each experiment in the spring, when the larvæ were most active, and a test was given in the fall just before their hibernation period. The last one was on a small scale and was carried on merely for the sake of added evidence.

Flowerpots were the cages used in the spring experiments. It was found that if the hole in the bottom was stoppered with cork, none would escape in the time of the experiment. It was also noted that where about half an inch of dry soil was placed on top of the damp soil of the cages the wireworms would never come entirely to the surface. This treatment, then, allowed the flowerpots to be buried to the surface of the soil out of doors, and with the exception that the larvæ were a little crowded it gave outdoor conditions.

In the first test of each experiment 50 larvæ were used and the test covered 20 days. In the two remaining tests in the spring 25 larvæ were used each time and the experiment was allowed to run for 30 days. In the experiments with deterrents the following substances were tested:

(1) Carbolic acid.
(2) Carbolic emulsion.
(3) Turpentine.
(4) Kerosene.
(5) Kerosene emulsion.
(6) Whale-oil soap.
(7) Potassium cyanid solution.
(8) Potassium cyanid solid.
(9) Copperas solution.
(10) Copper sulphate.
(11) Potassium sulphid solution.
(12) Tar water.
(13) Ash water.
(14) Nicotine sulphate.
(15) Free nicotine solution.
(16) Cresol (so-called coal-tar creosote).
(17) Salt solution.
(18) Lead chromate.
(19) Dry sulphur.

These deterrents were used on beet and lima-bean seeds, both of which are attacked by this species. It was hoped that in these experiments a deterrent could be discovered for protecting the tender roots until the plant had secured a fair start. If this could be accomplished the injury due to wireworms would be materially lessened.

CARBOLIC ACID.

Some seeds were soaked in a 10 per cent solution of carbolic acid overnight, were allowed to dry for some time, and were then planted in the pots. Fifteen were planted in the cage which contained the 50 larvæ. This cage was broken up in 20 days and examined, with the following results: Two seeds were destroyed before germination; seven after germination, and six were untouched; three larvæ were dead. In the check cage three seeds were untouched; most having been destroyed just after germination, and one larva was dead. The check cages gave even less favorable results, so it seems clear that the carbolic acid has little effect as a deterrent.

CARBOLIC EMULSION.

Carbolic emulsion was made by using the following ingredients in the proportions named:[1]

Crude carbolic acid	gallons..	5
Whale-oil soap	pounds..	40
Water (hot)	gallons..	40

The seeds treated were soaked in this emulsion overnight. After drying[2] in the sun for two hours they were planted. The results of the experiments are summarized in the following table:

TABLE II.—*Experiments with carbolic emulsion as a deterrent against the sugar-beet wireworm.*

	Larvæ used.	Seeds used.	Seeds attacked.		Seeds untouched.	Larvæ missing.	Larvæ killed by fungus.	Duration of test.
			Before germination.	After germination.				
								Days.
Experiment	50	15	2	7	6	3	0	20
Check	50	15	10	3	2	1	1	20
Experiment	25	10	1	7	2	3	0	30
Check	25	10	4	6	0	2	0	30
Experiment	25	10	3	5	2	1	2	30
Check	25	10	4	2	4	5	0	30

A glance at the foregoing summary shows that while carbolic acid might possibly be of value, it can not at this time be considered a practical remedy for wireworms.

TURPENTINE.

Seeds were soaked overnight in turpentine and after being allowed to dry were planted in the cages containing the wireworms. The turpentine had affected the seeds considerably and all of them were more or less "blistered."

[1] Essig, Pomona Journ. Ent., vol. 2, no. 3, p. 252, 1910.

[2] The seeds were dried in these experiments because, if used under field conditions, they would have to be treated in this manner before they could be used in a beet planter. This would be the only practical way the emulsion could be applied.

TABLE III.—*Experiments with turpentine as a deterrent against the sugar-beet wireworm.*

	Larvæ used.	Seeds used.	Seeds attacked.		Seeds untouched.	Larvæ missing.	Larvæ killed by fungus.	Duration of test.
			Before germination.	After germination.				
								Days.
Experiment	50	15	3	5	7	0	0	20
Check	50	15	3	4	8	0	0	20
Experiment	25	10	4	3	3	7	0	30
Check	25	10	5	2	3	1	1	30
Experiment	25	10	8	0	2	3	2	30
Check	25	10	7	3	0	4	1	30

A glance at columns 6 and 7 of Table III shows that there is little difference between the treated and untreated seeds—too little to promise much for this method.

KEROSENE.

Kerosene was given a trial as a deterrent in spite of the fact that it gave negative results in the experiments of Comstock and Slingerland. The seeds were treated by soaking in kerosene overnight. The kerosene in some instances removed part or all of the skin from the seeds. The results are summarized below.

TABLE IV.—*Experiments with kerosene as a deterrent against the sugar-beet wireworm.*

	Larvæ used.	Seeds used.	Seeds attacked.		Seeds untouched.	Larvæ missing.	Larvæ killed by fungus.	Duration of test.
			Before germination.	After germination.				
								Days.
Experiment	50	15	8	3	4	2	2	20
Check	50	15	12	1	2	0	6	20
Experiment	25	10	8	1	1	1	0	30
Check	25	10	10	0	0	4	1	30
Experiment	25	10	7	1	2	0	0	30
Check	25	10	8	2	0	0	0	30

This table shows that while treated seeds are a little less liable to attack before germination yet in the long run there is little difference between treated and untreated seeds. Germination tests carried on at the same time show that kerosene kills some of the seeds, so this would at least offset any benefits which might possibly be derived by protection.

KEROSENE EMULSION.

As the pure kerosene showed a weak tendency to keep the wireworms away temporarily it was thought that if some distasteful substance were mixed with it the combination of the two might be more successful. To this end kerosene emulsion was prepared by using whale-oil soap. The seeds were soaked in this overnight and then

dried in the sun. The seeds did not dry thoroughly and tended to adhere to one another. This would be a great disadvantage, as it would be hard to run these treated seeds through a planter. The following summary further shows its impracticability:

TABLE V.—*Experiments with kerosene emulsion as a deterrent against the sugar-beet wireworm.*

	Larvæ used.	Seeds used.	Seeds attacked.		Seeds untouched.	Larvæ missing.	Larvæ killed by fungus.	Duration of test.
			Before germination.	After germination.				
								Days.
Experiment	50	15	6	2	7	0	2	20
Check	50	15	10	3	2	1	1	20
Experiment	25	10	0	3	7	0	0	30
Check	25	10	4	6	0	2	0	30
Experiment	25	10	6	3	1	2	0	30
Check	25	10	4	2	4	5	0	30

WHALE-OIL SOAP.

The seeds used in the whale-oil-soap experiment were treated in two different ways. At first they were coated with the soap, but this method proved impractical (1) because the seeds could not be used in a planter and (2) because they tended to rot. The seeds were then treated by soaking in a concentrated water solution of the whale-oil soap. This second method overcame the objections to the first method. The results are summarized below.

TABLE VI.—*Experiments with whale-oil soap as a deterrent against the sugar-beet wireworm.*

	Larvæ used.	Seeds used.	Seeds attacked.		Seeds untouched.	Larvæ missing.	Larvæ killed by fungus.	Duration of test.
			Before germination.	After germination.				
								Days.
Experiment	50	15	10	2	3	0	0	20
Check	50	15	12	1	2	0	6	20
Experiment	25	10	4	3	3	0	3	30
Check	25	10	10	0	0	4	1	30
Experiment	25	10	6	4	0	1	0	30
Check	25	10	8	2	0	0	0	30

This table shows that the treatment of the seeds with whale-oil soap holds little promise of success.

TAR WATER.

Since satisfactory results in seed protection by coating the seeds with tar have been reported, it was thought possible that similar results might be obtained by soaking the seeds in tar water. In this way it should give the benefits of coating the seeds with tar,

and at the same time not have the disadvantage of causing the seeds to rot. This water is procured by allowing a mass of coal tar or pine tar to stand in water for some time. The water becomes slightly colored and smells very strongly of tar. A very little tar will suffice for treating a large amount of water.

The seeds were treated by allowing them to soak in this water overnight, and they were then planted. They smelled quite strongly of tar even after they were allowed to dry partially. The results obtained are shown in the following summary:

TABLE VII.—*Experiments with tar water as a deterrent against the sugar-beet wireworm.*

	Larvæ used.	Seeds used.	Seeds attacked.		Seeds untouched.	Larvæ missing.	Larvæ killed by fungus.	Duration of test.
			Before germination.	After germination.				
								Days.
Experiment	50	15	7	2	6	0	1	20
Check	50	15	3	4	8	0	0	20
Experiment	25	10	4	3	3	1	2	30
Check	25	10	5	2	3	1	1	30
Experiment	25	10	6	2	2	0	2	30
Check	25	10	7	3	0	4	1	30

In spite of the fact that the table seems to indicate that tar water is ineffectual, this method is to be given a more extensive trial next spring.

ASH WATER.

Ashes have long been used and recommended as a deterrent against various insects, and especially wireworms. It has been mentioned previously that the beetles appear to be driven out by ashes. About the only way that ashes could be used on a large scale would be to soak the seeds in water which had been used to leach out ashes. This method was used, the seeds being partially dried before planting. The following summary shows that any benefits which might have been derived from the use of this method are too small to be of much importance.

TABLE VIII.—*Experiments with ash water as a deterrent against the sugar-beet wireworm.*

	Larvæ used.	Seeds used.	Seeds attacked.		Seeds untouched.	Larvæ missing.	Larvæ killed by fungus.	Duration of test.
			Before germination.	After germination.				
								Days.
Experiment	50	15	5	5	5	0	2	20
Check	50	15	10	2	3	1	0	20
Experiment	25	10	6	2	2	7	0	30
Check	25	10	4	6	0	2	0	30
Experiment	25	10	7	1	2	2	1	30
Check	25	10	4	2	4	5	0	30

NICOTINE SULPHATE.

Some seeds were soaked overnight in nicotine sulphate and dried before planting. This sulphate, which is advertised to contain 40 per cent nicotine, is a dark, viscous liquid and smells very strongly of nicotine. When used pure it tended to rot many of the seeds. The best germination results were obtained when it was diluted about one-half with water. The summary shows that it could not be recommended as a deterrent.

TABLE IX.—*Experiments with nicotine sulphate as a deterrent against the sugar-beet wireworm.*

	Larvæ used.	Seeds used.	Seeds attacked—		Seeds untouched.	Larvæ missing.	Larvæ killed by fungus.	Duration of test.
			Before germination.	After germination.				
								Days.
Experiment	50	15	8	7	0	0	2	20
Check	50	15	10	3	2	1	1	20
Experiment	25	10	6	2	2	7	1	30
Check	25	10	10	0	0	4	1	30
Experiment	25	10	8	2	0	0	6	30
Check	25	10	7	2	1	0	0	30

FREE NICOTINE.

Seeds were soaked in nicotine solution overnight. This fluid, which contains free nicotine in water, has a very sharp nicotine odor and is also 40 per cent nicotine. As the results obtained in two out of the three tests were negative, its value as a deterrent must be slight. Some of the bean seeds were riddled by the wireworms. The results are shown below:

TABLE X.—*Experiments with free nicotine as a deterrent against the sugar-beet wireworm.*

	Larvæ used.	Seeds used.	Seeds attacked—		Seeds untouched.	Larvæ missing.	Larvæ killed by fungus.	Duration of test.
			Before germination.	After germination.				
								Days.
Experiment	50	15	4	7	4	0	3	20
Check	50	15	3	4	8	0	0	20
Experiment	25	10	3	3	4	3	0	30
Check	25	10	5	2	3	1	1	30
Experiment	25	10	7	2	1	0	2	30
Check	25	10	4	2	4	5	0	30

CRESOL.

Cresol, so-called coal-tar creosote, was tried in these experiments because it is used quite successfully in keeping dermestid larvæ out of collections. It is a thin liquid, rather dark in color, and with a strong tarry odor. The seeds were soaked in it overnight. The

results, which are summarized in the following table, do not promise much for the use of this substance in protecting seeds.

TABLE XI.—*Experiments with cresol as a deterrent against the sugar-beet wireworm.*

	Larvæ used.	Seeds used.	Seeds attacked—		Seeds untouched.	Larvæ missing.	Larvæ killed by fungus.	Duration of test.
			Before germination.	After germination.				
								Days.
Experiment	50	15	8	3	4	7	1	20
Check	50	15	10	2	3	1	0	20
Experiment	25	10	6	2	2	0	0	30
Check	25	10	4	6	0	2	0	30
Experiment	25	10	5	4	1	0	2	30
Check	25	10	7	3	0	4	1	30

OTHER SUBSTANCES TESTED AS DETERRENTS.

The other deterrents will be considered very briefly, since, with the possible exception of two, none gave much promise of ultimate success.

Copperas solution.—Seeds soaked overnight in a copperas solution, dried, and planted in the pots were almost as readily eaten as those in the check cages.

Copper sulphate.—Copper sulphate did not give much promise as a deterrent, as the seeds soaked in a solution of it overnight were eaten readily by the wireworms, and with apparently no ill effects.

Potassium sulphid.—Seeds treated with a concentrated solution of potassium sulphid appeared neither distasteful nor injurious to the wireworms.

Salt.—The seeds treated by soaking in a salt solution seemed for a time to be partially immune to the attack of wireworms. By the time several tests were completed, however, it was seen that while they were more immune from attack just before germination, enough were killed just after germination to make this procedure useless from a practical standpoint.

Sulphur.—Some seeds were coated with a paste made of equal parts of sulphur and flour, and after being allowed to dry were planted. When examined later many had rotted and the rest had been riddled by the wireworms. Some of the larvæ were partially covered with sulphur, but did not seem in the least inconvenienced. It was considered that this experiment would give negative results, since the sulphur, kept under the damp cool soil, would not give off fumes to any extent, and hence its best effect would be lost.

Lead chromate.—Seeds treated as in the foregoing experiment, but using lead chromate in place of sulphur, were not protected in the least, nearly every seed being drilled through in several places.

THE USE OF POTASSIUM CYANID AGAINST THE WIREWORMS.

Potassium cyanid was one of the first remedies tested for the wireworms, because it has the properties both of an excellent deterrent and a deadly poison. Used as a deterrent, the seeds were treated in two different ways. In the first the cyanid was used as a solid and drilled in with the seed. This method affords excellent protection to the seed, but the drawbacks connected with it have thus far made it impracticable. The cyanid burns the seed wherever it comes in contact with it, and when germination begins, it burns the tender roots. Another argument against its use for this crop is its cost. In the second method of seed protection the seeds were soaked overnight in a solution of cyanid in water, dried, and planted. In this method it was also quite effective as a deterrent, but unfortunately its effects on the roots were such that it could not be used. At the present time it seems very doubtful if the cyanid can be used in such a strength that it will keep away the wireworms and at the same time not harm the plants. This point is going to be tested further.

While these experiments were being carried on it was noted that in some of the cages most or all of the wireworms had been killed. These larvæ had the appearance of having been killed by a fungus, but as their bodies were not filled with the fungus it was apparent that they had been killed in some other way. It was thought that perhaps they had been killed by the fumes of the cyanid, and later experiments seemed to bear out this point. With this in view, many experiments were carried on in an attempt to discover some good method for the application of the cyanid. From these, two plans were selected for final trials, one in which the cyanid was used as a solid, and the other in which it was used as a liquid. The results are given below.

According to the first plan the cyanid was drilled into the ground much after the method used for fertilizers. This plan was finally given up, as the cyanid was not distributed evenly through the soil, and therefore had to be applied more heavily than was necessary in order to be effective. As the cyanid is very destructive to plant growth it is readily seen that it would have to be used as sparingly as possible.

The method of using the liquid consisted in making a solution of the cyanid in water and applying it evenly over the land. This could then be made to permeate the soil to any depth by irrigation. By this method the cyanid is used sparingly, as it is evenly applied. Unfortunately it has been impossible to try this remedy thoroughly, up to the present time. In all the experiments where this method was employed its killing power was very good. To test it further, it was applied in a cage containing beets, with the result that both

beets and wireworms were killed. It was used several times more, and in weakened solutions, but invariably the results were the same. By this time the season was so far advanced that experiments along this line had to be given up for the year. The conclusions that seem justified from this experiment at the present time appear to be that the wireworms may be killed by applications of a solution of potassium cyanid to the soil, but that the beets are also killed by the same treatment. It is a question whether a certain strength of cyanid can be found which will kill the wireworms and spare the beets. Possibly, however, the wireworms can stand a stronger application of the cyanid than the beets can. As this is the only insecticide which has given promise of good results against the wireworms, it will receive further careful tests. The possible effect of this cyanid on the soil and future crops is also an interesting question, and one which will have to be investigated. There is a possibility that this cyanid might be applied directly after the crop is removed and before the wireworms have become dormant for the winter.

EXPERIMENTS WITH POISONED BAIT AGAINST THE WIREWORMS.

In the experiments in the use of poisoned bait against the wireworms the points which were chosen for solution were, (1) to find a substance for the bait which would be very attractive to the wireworms, and (2) to find a poison to go with it which would certainly kill the larvæ. Thus far success has not been attained in the solution of either. The following materials have been experimented with as bait:

Beans.
Corn.
Cornmeal.
Bran.
Alfalfa meal.
Shredded beets.

Of these the only ones which have proved attractive enough to be used with the poisons were beans, corn, and shredded beets. Series of experiments were conducted using each bait with every poison, and checks were employed in each. The following poisons were used:

(1) Lead chromate.
(2) Potassium cyanid.
(3) Strychnine.
(4) Paris green.
(5) Lead arsenate.
(6) Zinc arsenite.

The first four named, being insoluble, were applied to the bait in paste form with flour. In the case of every poison except the cyanid the wireworms were observed eating the bait, and if they suffered any ill effects from it they failed to show it to a noticeable degree. The bait containing the cyanid was eaten sparingly on account of its deterrent qualities. Wireworms were found dead in some of the cages in which potassium cyanid was used, but whether their death

FIG. 1.—FIELD OF YOUNG BEETS AT AGE WHEN THEY BEGIN TO BE PARTIALLY SAFE FROM SEVEREST INJURY BY THE SUGAR-BEET WIREWORM. (ORIGINAL.)

FIG. 2.—BEET FIELD, SHOWING CONDITIONS FAVORABLE FOR INCREASE OF WIREWORMS. WEED HEDGES WHICH SHELTER ADULTS IN SECONDARY HIBERNATION. (ORIGINAL.)

CONDITIONS FAVORING THE SUGAR-BEET WIREWORM. BEET FIELD IMMEDIATELY AFTER HARVEST, SHOWING BEET TOPS CARELESSLY SCATTERED OVER GROUND. (ORIGINAL.)

CLEAN CULTURE AGAINST THE SUGAR-BEET WIREWORM. NATURAL METHOD OF CLEARING OFF BEET TOPS BY PASTURING CATTLE IN THE FIELD WHICH HAS BEEN INCLOSED BY A TEMPORARY FENCE. (ORIGINAL.)

CLEAN CULTURE AGAINST THE SUGAR-BEET WIREWORM. COLLECTING THE BEET TOPS IN PILES AND HAULING THEM FROM THE FIELD AS FOOD FOR STOCK. (ORIGINAL.)

FIG. 1.—BEET FIELDS SEPARATED BY STRIP OF ALFALFA. (ORIGINAL.)

FIG. 2.—FIELD OF ALFALFA ADJOINING FIELD OF SUGAR BEETS. (ORIGINAL.)

CONDITIONS FAVORING THE SUGAR-BEET WIREWORM.

was due to eating the poison or to the effect of fumes has not been determined.

The results in the use of strychnine and potassium cyanid have been quite well verified in an entirely independent series of experiments carried on by Mr. R. S. Vaile.

From the foregoing it can be seen that the experiments thus far tried in the use of poisoned bait against the sugar-beet wireworm have been far from satisfactory. They are to be continued in future work.

EXPERIMENTS WITH GUANO FERTILIZER.

The only fertilizer tested on the wireworms was a mixture of bird and bat guano, a South American product, which is chiefly nitrogenous and is characterized by a strong and lasting odor of ammonia. It was hoped that the strong ammonia odor would drive the wireworms deeper into the soil. The results from its use thus far—it has been tried only on a small scale in the laboratory—seem to indicate that it would have to be used at the rate of from 8 to 10 tons per acre to be partially effective. As this is many times heavier than an average dressing for the soil it would probably be impractical to use it.

PROTECTION OF BEETS BY EARLY PLANTING.

The protection of beets by early planting is a remedy which was early suggested by Mr. H. M. Russell and has since been given a practical test on a large scale. The advantage of this method is very plain. When the beets are planted early the plants are quite hardy and the roots are swollen by the time the wireworms are doing their worst injury. (See Pl. XIX, fig. 1.) These swollen roots can stand a severe attack without having their sap supply cut off, and in consequence a much smaller number of them are killed.

Mr. H. J. Mayo, one who grows sugar beets on a large scale in both Los Angeles and Orange Counties, writes as follows concerning early planting:

* * * In the season of 1911 I planted early and the results were very good, especially on the heavy land, as the beets seemed to get a start, and the worms did not seem to affect them so much, although they were in the ground and from examinations that I made they worked on the beets; but where the beets got the start the worms did not bother them so much.

In my opinion early planting will relieve a great deal of the danger of the wireworm.

Clean Culture against the Adults.

The following in regard to remedial measures is the result neither of theory nor of experiment. It was suggested to the writer by observations taken in the field at the time the hibernating beetles

were being collected. It was suggested also by the different states of affairs noted in different fields where various systems of culture had been practiced. These observations were carefully made in fields aggregating over 600 acres, and daily during a period covering about two months.

Two different methods are practiced by the growers in disposing of the beet tops which remain in the field (see Pl. XX) after the crop has been harvested. Some growers leave them in the field to be plowed under and act as a fertilizer, while others use them for stock feed. In the latter method, which may be spoken of as clean culture, the beet tops are either disposed of by pasture (Pl. XXI) or they are hauled from the field (Pl. XXII). The tops are removed best by pasturing either with cattle or sheep.

The tops which are left for fertilizer are supposed to be plowed under, but by the time the land has been harrowed several times, and planted, not a few have reappeared on the surface. Then as the beetles appear in the spring and enter their secondary hibernation they find excellent shelter and feeding places (see Pl. XIX, fig. 2), and most of them remain in the field near the place where they emerged and are able to pass this critical period of their lives safely. On the other hand, where the tops and old beets have been cleared off, the beetles find no place to hide, and consequently move to other fields in search of shelter. Very few can hide under clods or in the soil on account of intermittent rains.

One illustration of the effects resulting when beets are left in the fields will be sufficient, for this same state of affairs was found to exist in all the fields examined.

The beet fields *A*, *B*, and *C* adjoined one another as shown in the diagram (fig. 9). At the right of *C* was a field of alfalfa. In *A* the beet tops had been left in the field to act as a fertilizer; in *B* and *C* they had been cleared off. During the preceding year the field *C* had suffered from wireworm injury as much, if not more, than any field in the Compton district. On this account there must have been many mature wireworms there, and consequently many beetles emerging, yet when the beetles were collected in these fields hardly any were found in *B* and *C*, and they were taken in *A* literally by thousands. As an experiment, about 50 old beets were scattered in the field *C*, along the line *c c*. These beets were inspected daily from this time on, and found to shelter large numbers of adults, even though none had been taken previously in *C*. Conditions in the other two fields remained as before, no beetles, or very few, being found in *B* while *A* yielded its usual number.

A simple conclusion can be drawn from these observations. The beetles collected only where they could find shelter, and those which emerged from perfectly clean fields had either to move to other fields

where they could find shelter or to remain where they were, exposed to the attacks of their predaceous enemies, the birds. In the instance cited probably many were eaten by birds, as these were quite abundant at the time, and the fields were bare.

In the observations dealing with the dispersal of the beetles throughout the fields it was determined that for the greater part the beetles remain and lay eggs near the place where they have been feeding. From this it is easy to see that in the fields which contain the greatest number of old beets and beet tops the largest number of beetles will deposit their eggs. As the wireworms can not travel very far from where the eggs are laid it is readily seen that large numbers of beetles in a field are the forerunners of large numbers of wireworms in that field later, with their resulting injuries to the crop.

A condition leading to the successful hibernation and dispersal of wireworms is illustrated in Plate XXIII, figures 1 and 2. In these instances the immediate proximity of alfalfa fields to those containing beets affords effective shelter for the hibernating beetles, and, as alfalfa is only second as a host to beets, provides abundant food for a continual supply of larvæ and adults. Reinfestation under such conditions is naturally very likely to occur through the migration of the beetles from the alfalfa to the beets, and both crops may thus be injured.

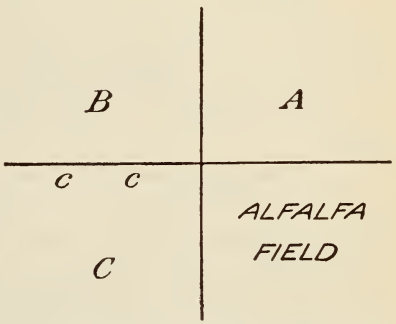


FIG. 9.—Diagram of beet fields, to illustrate the effect of clean culture in reducing injury by the sugar-beet wireworm. (Original.)

The main drawback to clean culture is that even where it is practiced faithfully several years must pass before positive results will be apparent. As has been stated, the same thing is true with regard to fall plowing for the destruction of the pupæ. This would be advantageous in one way, however, in that the benefits would be felt for two years after the treatment had been discontinued. The main difficulty is that a grower, after practicing this remedy for two years, might suffer heavily from wireworm injury, become discouraged, and stop the treatment. The only way to give this remedy a fair trial would be to practice it faithfully and wait until the third or, better, the fourth year before drawing conclusions.

The greatest advantage of this remedy is that it is entirely feasible and, being cultural in character, is also entirely practical, regardless of the crop grown. For the best results it should be practiced in conjunction with fall plowing, and to reduce the injury from the wireworms already in the soil early planting should be employed.

Considering that all the growers have idle horses during the late fall, the plowing would not appear to be a large item of expense, especially when its value to the soil is taken into consideration.

In conclusion it may be safely stated that the clean-culture remedy, especially when reenforced by fall plowing and early planting, is easily the most promising remedy which has thus far come under observation during the sugar-beet wireworm investigations.

SUMMARY.

(1) The sugar-beet wireworm kills the beet plant by injuring the root. It is most injurious while the beets are young and is destructive only in the wireworm or larval stage.

(2) The life cycle probably covers four years. About one month each is required for the egg and pupal stages; seven to nine months for the adult stage, during the greater part of which the beetle is in hibernation; and about three years, or the rest of the time, for the larval stage.

(3) Thus far it seems to be impractical to employ remedies against the larvæ. As these live underground and are protected by a thick integument it is difficult to injure them. They also seem able to eat a certain quantity of many poisons and deterrent substances with safety.

(4) Plowing in the fall is a fair remedy against the pupæ, but at that time of the year the soil is dry in southern California and is turned up in large clods; consequently many pupæ escape destruction.

(5) Much of the injury to the beets may be avoided by early planting, thus giving the roots a good start before the wireworms are doing their most extensive feeding.

(6) Clean culture against the adults, by compelling them to seek shelter elsewhere and exposing them to the attacks of their bird enemies, seems to be the most practical remedy found thus far for this insect. The efficiency of this remedy would be increased if fall plowing and early planting were used with it.

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INDEX.

Page.

Alfalfa, food plant of *Limonius californicus* 11, 16, 17, 35
meal, poisoned, as bait for sugar-beet wireworm 60
Amaranthus retroflexus, food plant of *Limonius californicus* 16
Arsenate of lead in poisoned baits against sugar-beet wireworm 60
beetles 51
Arsenite of zinc in poisoned baits against sugar-beet wireworm 60
beetles 51
Ash water against sugar-beet wireworm 52, 56
Aster, wild, food plant of *Limonius californicus* 16
Bacterial diseases of *Limonius californicus* larvæ 48–49
Beans, food plants of *Limonius californicus* 12, 16, 17
poisoned, as bait for sugar-beet wireworm 60
Beet roots, food of *Limonius californicus* beetles 35–36
sugar, food plant of *Limonius californicus* 11, 12, 16, 17
Beets, injury by wireworms, *Limonius californicus* 26–27
shredded, poisoned, as bait for sugar-beet wireworm 60
Blackbird, Brewer's. (See *Euphagus cyanocephalus*.)
"Blacksmiths," colloquial name for Elateridæ 13
Blapstinus sp. in sugar-beet fields with *Limonius californicus* 13
prey of *Lanius ludovicianus gambeli* 46
Bran, poisoned, as bait for sugar-beet wireworm 60
Brassica niger, food plant of *Limonius californicus* 16
Cages for rearing *Limonius californicus* 21–22, 36–37
Calosoma cancellatum, enemy of *Limonius californicus* 47, 48
semilæve, enemy of *Limonius californicus* beetles 47
Carabidæ, enemies of *Limonius californicus* beetles 47
Carbolic acid and carbolic emulsion against sugar-beet wireworm 52, 53
Cardiophorus æneus, in sugar-beet fields, comparison with *Limonius californicus*. 13
californicus = *Limonius californicus* 13
original description 14
crinitus (?), in sugar-beet fields, comparison with *Limonius californicus* 13
Chordeiles virginianus henryi, enemy of *Limonius californicus* beetles 47
Chrysanthemum, food plant of *Limonius californicus* 16
Coniontis sp. in sugar-beet fields with *Limonius californicus* 13
Copperas solution against sugar-beet wireworm 52, 58
Copper sulphate against sugar-beet wireworm 52, 58
Corn, food plant of *Limonius californicus* 11, 12, 16, 17
meal, poisoned, as bait for sugar-beet wireworm 60
poisoned, as bait for sugar-beet wireworm 60
Creosote, coal-tar. (*See* Cresol.)
Cresol against sugar-beet wireworm 52, 57–58
Culture, clean, against sugar-beet wireworm adults 61–64
Dock. (See *Rumex hymenosepalus*.)
Drasterius livens, in sugar-beet fields, comparison with *Limonius californicus* ... 12, 13

Page.
Early planting against sugar-beet wireworm 61
Elaterids in sugar-beet fields, comparison with *Limonius californicus* 13
Euphagus cyanocephalus, enemy of *Limonius californicus* beetles 47
Flycatcher, ash-throated. (See *Myiarchus cinerascens cinerascens.*)
Fungous diseases of *Limonius californicus* 47–48, 49–50
Grass, Johnson. (See *Sorghum halepense.*)
Ground-beetles. (*See* Carabidæ.)
Guano fertilizer against sugar-beet wireworm 61
Gull, sea. (See *Larus* sp.)
Insects found with *Limonius californicus* 12–13
Johnson grass. (See *Sorghum halepense.*)
Kerosene against sugar-beet wireworm 52, 54, 55
emulsion against sugar-beet wireworm 52, 54–55
Killdeer. (See *Oxyechus vociferus.*)
Lanius ludovicianus gambeli, enemy of *Blapstinus* sp. 46
Limonius californicus beetles 46, 47
Larus sp., enemy of *Limonius californicus* 48
Lead chromate against sugar-beet wireworm 52, 58, 60
Limonius californicus, adult, ability to withstand unfavorable conditions 40
activity, beginning of period 33–34
appearance in spring 33
cages used in rearing 36, 37
description 14
duration of life under varying conditions 37–38
effect of temperature thereon 39, 40
emergence 32
actions thereafter 41–42
period 32
endurance when submerged in water 38
life history and habits 32–42
mating 40–42
actions thereafter 41–42
oviposition 42
variation 34–35
adults from emergence to hibernation 42–43
bibliography 64
classification 13
control, natural 46–50
descriptions of stages 14–16
distribution 16
dissemination 45, 46
egg, description 14
length of stage 20
life history 18–20
time and place of deposition 18–19
eggs, number and hatching 19–20
emergence from hibernation gradual 43–44
enemies and checks 46–50
food plants 16–17, 35–36
fungi affecting pupæ and eggs 49–50
habits and life history 18–42
hibernation 43
"secondary" 33, 44–45

Page.
Limonius californicus, historical 11
injury to beets 26–27, 29
insects found therewith 12–13
larva, description 14–15
duration of life without food 27–28
emergence from egg 20
habits 22–26
injury to beets 26–27
length of stage, approximate 24
life history and habits 20–30
molting 29–30
newly hatched 20–21
rearing cages used 21–22
relation between size and abundance and injury in beet fields 29
life cycle, approximate length 42
history and habits 18–42
losses due to work 11–12
mating 40–41
mortality during hibernation 43
names, common 13
occurrence of beetles in field 45
oviposition 42
pupa, changes in color 31
description 15–16
length of stage 31
life history 30–31
vitality 31
pupal cell 30
pupation 30–31
remedial measures 50–64
deterrents against larvæ, experiments 52–60
fall plowing for destruction of pupæ .. 51
historical 50
poisoned baits 50–51
seasonal history 42–46
soil conditions affecting pupation 30–31
summary 64
synonymy 13
Lophortyx californicus vallicola, enemy of *Limonius californicus* 47
Meadowlark, western. (See *Sturnella neglecta.*)
Medicago spp. (*See* Alfalfa.)
Mustard. (See *Brassica niger.*)
Myiarchus cinerascens cinerascens, enemy of *Limonius californicus* 47
Nettle, food plant of *Limonius californicus* 16
Nicotine, free, solution, against sugar-beet wireworm 52, 57
sulphate against sugar-beet wireworm 52, 57
Nighthawk, western. (See *Chordeiles virginianus henryi.*)
Oxyechus vociferus, enemy of *Limonius californicus* 47
Paris green in poisoned baits against sugar-beet wireworm 51, 60
Pigweed. (See *Amaranthus retroflexus.*)
Platynus sp. in sugar-beet fields with *Limonius californicus* 13
Potassium cyanid and flour in poisoned baits against sugar-beet wireworm 60

Page.
Potassium cyanid, solid, against sugar-beet wireworm 52, 59–60
solution against sugar-beet wireworm 52, 59–60
sulphid solution against sugar-beet wireworm 52, 58
Potato, food plant of *Limonius californicus* 16, 17
Quail, valley. (See *Lophortyx californicus vallicola.*)
Rumex hymenosepalus, food plant of *Limonius californicus* 16
Salt solution against sugar-beet wireworm 52, 58
Shrike, California. (See *Lanius ludovicianus gambeli.*)
"Skipjacks," colloquial name for Elateridæ 13
Soap, whale-oil, against sugar-beet wireworm 52, 55
Solanum tuberosum. (*See* Potato.)
Sorghum halepense, food plant of *Limonius californicus* 16, 35
Sparrow, native, enemy of *Limonius californicus* beetles 47
"Spring-beetles," colloquial name for Elateridæ 13
Storms as checks to *Limonius californicus* beetles 47
Strychnine in poisoned bait against sugar-beet wireworm beetles 51, 60
Sturnella neglecta, enemy of *Limonius californicus* beetles 47
Sugar-beet wireworm. (See *Limonius californicus.*)
Sulphur, dry, against sugar-beet wireworm 52, 58
Tar water against sugar-beet wireworm 52, 55–56
Temperature as affecting adult *Limonius californicus* 39
Turpentine against sugar-beet wireworm 52, 53–54
Variation in beetles of *Limonius californicus* 34–35
Wireworm, lesser sugar-beet, undetermined species near *L. californicus* 13
Wireworms found in sugar-beet fields 12–13

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